The spread and impacts of invasive non-native plants in a human-dominated landscape: The case of Japanese knotweed

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I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

Signature:

There must have been plenty of them about, growing up quietly and inoffensively, with nobody taking any particular notice of them... And so the one in our garden continued its growth peacefully, as did thousands like it in neglected spots all over the world... It was some little time later that the first one picked up its roots and walked.

John Wyndham, The Day of the Triffids

Abstract

The increased movement of plants around the world is a serious and impactful environmental consequence of increased human dominance globally. Some of these plants will become established in new areas, some will proliferate, and some will become invasive causing environmental and socio-economic damage. Environmental processes contribute to plants becoming introduced, established and invasive. However, humans have an increasingly important role in all stages of the invasion process. In particular, the social processes that shape decision making, such as knowledge, risk perceptions, values and attitudes, can influence people's behaviour that might lead to increased or decreased spread of invasive non-native plants (INNP). The social processes contributing to individual decision-making can be particularly influential in domestic gardens as it is the individual(s) responsible for that garden that decides how it is managed. Furthermore, the socio-economic impacts of INNP can be particularly acute in domestic gardens. In addition to the direct impacts of INNP in domestic gardens, an increase of their abundance therein could be detrimental to the health and well-being benefits gardens can provide, such as increased connectedness to nature.

Invasion ecology is a rapidly growing area of research, however, key gaps in knowledge remain. In particular, little research has been done on INNP in domestic gardens and the perceptions of risk people have about the impacts they can have therein. This thesis applies an interdisciplinary approach to address these gaps. Japanese knotweed *Fallopia japonica,* is used as a case study throughout as it exemplifies many of the environmental and socio-economic impacts of INNP, many of which are particularly acute in domestic gardens.

Identifying the processes contributing to the spread of INNP will help develop mitigation strategies to reduce their spread and therefore impact - this is the focus of chapters two to six. Chapter two explores the predictors of presence and abundance of Japanese knotweed at a 1km resolution within Cornwall, UK, finding that building density is the strongest predictor, followed by biophysical variables (minimum and maximum monthly temperature), and then socio-economic status of the residents within the 1km grid-cell. Chapter three considers one social process that might be contributing to the spread of INNP - the movement of propagules within soil. One of the key results of this chapter is

that the abundance of invasive and naturalised species was significantly higher in garden than in housing development samples. This suggests that informal movement of soil between gardens poses a greater risk of spreading invasive plants than do commercial sources. Chapter three highlights the importance of high levels of identification skills of INNP to reduce their spread, however no previous research has tested INNP identification levels amongst the public. Chapter four explores this idea, finding that less than 20% of the public could identify Japanese knotweed. Even if people can identify INNP, if it is present in their garden they may not know how to manage it correctly and details of the impacts it can have therein. Chapter five analyses internet-based information about the management advice and impacts of INNP, determines the authors of this discourse, and considers whether and how this could be confusing to those responsible for managing domestic gardens. Analysis identified extensive variation in document structure, topics discussed, references and links to other sources, and language style; sometimes this variation was between and sometimes within author categories. A key conclusion from chapter five is that some internet-based information sources might potentially contribute to amplification (or attenuation) of risk perceptions, that could in turn lead to inappropriate management actions, resulting in increased spread of INNP. Chapter six uses a survey approach to explore risk perceptions of INNP in domestic gardens further. The results suggest differences in perceived risk of Japanese knotweed depends on people's occupation, their direct experience of the species in a domestic context, their geographical proximity to the risk, their age and level of education.

Greater understanding of the impacts INNP can have within domestic gardens will help assess the level of risk, plan mitigation strategies and design risk communication. This is the focus of chapter seven, which focuses on the economic impacts within domestic gardens. Results indicate that the magnitude and frequency of the risks Japanese knotweed poses in domestic gardens are much lower than anticipated based on media coverage, and compared with public perception.

The results of this thesis have several important implications: (1) To mitigate potential inaccurate perceptions of INNP, governmental authorities need to provide clear and accurate communication about the impacts of INNP and how best to manage them. (2)

When resources are limited, identifying the areas of society where knowledge is lowest or perceptions most inaccurate can help awareness and educational campaigns to be more impactful, thus reducing spread and impacts of INNP. (3) Implementation of the recommendations to reduce the spread and impacts of INNP within domestic gardens given within this thesis could contribute towards preserving the health and well-being benefits gardens can provide. Overall this thesis demonstrates further evidence of the need to consider the human causes and solutions to INNP and the need for knowledge on this topic to be applied by a diverse range of stakeholders.

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Table of Contents

LIST OF TABLES

LIST OF FIGURES

Chapter eight: discussion

Chapter one

Introduction

1.1 Introduction

Humans are having a persistent, pervasive and increasingly concerning impact on the global environment (Vitousek 1997; UN 2010), due to increasing populations, consumption, travel and trade (Meyerson & Mooney 2007; Banks *et al.* 2014). One of the most striking ways this is manifesting itself is by the increased movement of plants around the globe (Simberloff *et al*. 2013; Kumschick *et al.* 2014), some of which will become invasive and have serious and widespread ecological and socio-economic impacts (Vilà *et al.* 2011; Jeschke *et al.* 2014). The spread and impacts of invasive non-native plants (INNP) are amplified through synergistic interactions with other dimensions of global change (Theoharides & Dukes 2007), for instance, climate change, land use change, habitat exploitation and increasing concentrations of atmospheric carbon dioxide (Pyšek & Richardson 2010).

Invasion ecology is a rapidly growing research area (Hulme 2006; Simberloff 2015). However, the terms 'non-native' and 'invasive' are still viewed as somewhat subjective and have been the subject of considerable academic debate in recent years (Richardson *et al.* 2000; Colautti & MacIsaac 2004; Davies *et al.* 2011). A 'non-native' species is generally thought of as one that has been intentionally moved from a geographic area other than the one it originally occupied (Selge *et al.* 2011), although debate exists about the most appropriate spatial and temporal scale to use (Boonman-Berson *et al.* 2014; Jeschke *et al*. 2014). Within this thesis, unless otherwise stated, I consider any plant introduced into a new country since 1500AD a non-native. An 'invasive' species is viewed by some as a species outside its natural range that spreads and maintains itself without human assistance (Richardson *et al*. 2000). However, some argue the definition should only include species that have net negative ecological or social-economic impacts (Selge & Fischer 2011; Schlaepfer *et al.* 2012; Hulme *et al.* 2013) – this is the definition I shall use in this thesis. The debate is extended further when one considers that not all species termed ‘invasive’ have to be non-native and many argue that species should be judged on their impact rather than their origin (Head & Muir 2004; Davies *et al.* 2011). Consider, for example, brambles *Rubus fruticosus spp*. agg, in the UK, which grows rapidly and can be problematic to eradicate if undesired.

1.2 The plant invasion process

There are multiple stages preceding a plant becoming invasive and problematic, outlined in Figure 1.1. These stages are not discrete and depend on the spatial and temporal scale in question, however they provide a useful framework for exploring the invasion process. The processes influencing the different stages can be categorised as ‘environmental’ and ‘human-dimensions’. Although it is important to consider the environmental factors, there is increasing recognition that to better comprehend the invasion process it is necessary to appreciate the magnitude of the role that humans have in the different stages of invasion (Robbins 2004; Hulme 2009; Wilson *et al*. 2009; Simberloff *et al.* 2013). Similarly, plant invasions can impact on the environment and\or humans (Simberloff *et al.* 2013). Below I explore the environmental and human-dimensions of the spread and impacts of invasive non-native plants (INNP) in turn.

1.2.1 Environmental dimensions of the invasion process

The spread of INNP is governed by multiple stages involving complex processes and interactions (Meyerson & Mooney 2007; Figure 1.1, part a). The first, ‘introduction’, involves the transportation of seeds or vegetative fragments to new geographical areas. The processes that determine the ‘introduction’ stage can be abiotic, for example wind blowing seeds around, or biotic, for example animals transporting seeds that become attached to them (Ruxton & Schaefer 2012). The likelihood of introduction depends also on the biotic traits of the species (Hamilton *et al.* 2005, van der Veken *et al*. 2007). Certain traits of the propagule will increase the likelihood of introduction (Ruxton & Schaefer 2012), for example, morphological adaptations to enable long distance dispersal by wind or adherence to animals. Likewise, anything that increases propagule pressure, that is, the number and frequency of release events, for example, prolific seed production (van der Veken *et al.* 2007; Lockwood *et al.* 2005), will increase opportunities for introductions (Meyerson & Mooney 2007; Wilson *et al.* 2009). However, methodological complications and the subjectivity involved in defining 'non-native species' make identifying characteristics that increase propagule pressure problematic.

Only a small proportion of species (as a very approximate rule 10%) that are introduced into a new area will become established, of which only a small proportion (approximately 10% again) will become invasive (Williamson & Fitter 1996; Hayes & Barry 2008). The environmental conditions into which plants are introduced play a role in determining chances of establishment and invasion (Maskell *et al.* 2006). In particular, processes that increase physical disturbance or nutrients increase the likelihood a non-native plant will become established and invasive (Lake & Leishman 2004).

Predicting which species will become established and invasive is not straightforward (Colautti *et al.* 2006). However, research has repeatedly demonstrated that strategies that increase carbon capture abilities of the plant, such as specific leaf area (Leishman *et al.* 2014) and extended flowering period (Lake & Leishman 2004), increase the likelihood of a species becoming established, widespread and invasive. Furthermore, as with introduction, anything that increases propagule pressure will increase the probability of establishment and proliferation (Colautti *et al.* 2006). Predicting which species will become invasive (will have net negative ecological and socio-demographic impacts) rather than just becoming widespread, is difficult (Leishman *et al.* 2014).

1.2.2 Human-dimensions of the invasion process

Humans are a major factor influencing the spread of INNP at every stage of the invasion process (Thuiller *et al.* 2006; Brown *et al.* 2008). At the introduction stage, humans are the strongest biotic determinant as they greatly increase propagule pressure (Simberloff *et al.* 2013), and are more likely to transport propagules over longer distances than environmental processes (Theoharides & Dukes 2007). Humans introduce plants to new areas intentionally and unintentionally (Hulme 2009), both of which are largely driven by increased global trade and travel (Dehnen-Schmutz *et al.* 2007a; Banks *et al.* 2014). Unintentional introductions, for instance, seeds transported between continents when lodged in shoes of airplane passengers (Ware *et al.* 2011), have continued to increase relative to intentional introductions throughout the 20th century (Hulme *et al.* 2008), and show little sign of abating (Hulme 2009). Historically, intentional introductions through the ornamental horticultural trade were the most common method of anthropogenic introduction of non-native plants (Dehnen-Schmutz *et al.* 2007a). Many ornamental plants planted in gardens then escape into the wider environment (Groves *et al*. 2005; Lambdon *et al.* 2008). For example, in Australia, 66% (1,831 out of 2,799) of introduced plant species that have become established in the wild originated from domestic gardens (Groves *et al*. 2005).

The ways in which humans modify environments makes them more susceptible to the establishment and invasion of non-native plants (Hansen & Clevenger 2005). For example, by creating elevated levels of disturbance (González-Moreno *et al*. 2015) and available nutrients (Maskell *et al*. 2006). In this way, INNP are products, as well as drivers of global environmental change. Anthropogenic activity that causes a plant to become invasive might happen a long time after the species was introduced into the area. The Tree Mallow *Lavatera arborea*, for example, although introduced to Scotland three centuries ago, has only become invasive in the last two decades due to human induced changes to the habitat (Fischer & van der Wal 2007).

The social processes that drive decision making of individual people can influence every stage of the invasion process (Head & Muir 2004). For example, at the introduction stage, aesthetic preferences for certain plants, or requirements / desires for non-native plants with practical uses, can have a strong effect (Kendal *et al*. 2011; van Heezik *et al*. 2014). The latter will, of course, depend on people's knowledge and perception of the potential practical uses or economic value of the species (Perrings *et al.* 2002). Knowledge and perceptions will also play a strong role in the establishment and invasion stage. For example, knowledge of management practices and legislation will influence what management approaches people choose to reduce the establishment and spread of plants. Likewise, perceptions and understanding of the different ecological and socio-economic risks of particular INNP, or INNP in general, will influence how individuals manage, or don't manage, the plants. All these social processes are likely to interact in complex ways (Head & Muir 2004). The social processes governing decision-making are particularly significant when considering INNP within domestic gardens, as the way in which they are managed (or not) depends greatly on the actions taken by individuals responsible for them (Qvenild *et al.* 2014).

1.2.3 Environmental impacts of INNP

INNP can have serious and widespread ecological impacts (Kumschick *et al.* 2014). Most conspicuously, INNP can reduce species richness and abundance of native species (Vilà *et al.* 2011). They can also have many subtler effects, for example they can alter the seed bank and change the chemical composition of soil making an area more susceptible to secondary invasions (Gioria & Pyšek 2015), they can reduce genetic diversity by hybridizing with native plants (Vilà *et al.* 2000), and in some cases they have been implicated in the extinction of plants (Simberloff 2015). These impacts can have multiple repercussions for other trophic levels and ecosystem function (Pyšek *et al.* 2012).

1.2.4 Socio-economic impacts of INNP

Many INNP also have socio-economic impacts (Figure 1.1, part b; Pejchar & Mooney 2009; Vilà *et al.* 2010). Some INNP can cause harm to human health (Hulme 2006), for example giant hogweed *Heracleum mantegazzianum* can cause burns upon contact with human skin (Henry *et al.* 2009). The rapid and dense spread of some INNP can restrict access for recreational activities, for example to lakes and rivers (Pimentel *et al.* 2005; Vilà *et al.* 2010). Some individuals may choose to avoid areas where invasive species are present due to the effect these have on the aesthetics of the landscape (Jones 2016). Many INNP have associated economic costs, which can be high (Pimentel *et al.* 2009). This might be the cost of control; one study estimated that the cost of pesticides to control 30 INNP in the UK exceeded €150 million per year (Williamson 2011). Alternatively, economic losses might be due to less conspicuous costs, such as loss of crop yield (McLaughlan *et al*. 2014).

As well as the previously mentioned role of domestic gardens as a source of INNP spread, INNP can also have notable impacts within domestic properties. The control / eradication costs of INNP in gardens can be high, and are usually the responsibility of the owner of the property (Qvenlid *et al.* 2014). Costs might include pesticides, hiring professional assistance and waste disposal (McDermott *et al*. 2013). Further costs can sometimes arise, for example if the INNP spreads to adjacent land it can result in legal proceedings (van Ham *et al.* 2013), and sometimes - although examples are rare - INNP can reduce property prices when nearby (Olden & Tamayo 2009).

Evaluating the costs and benefits of INNP is not always straightforward. Some INNP can have net benefits (Simberloff *et al.* 2013), for example the invasive Australian Red Claw crayfish *Cherax quadricarinatus* provides an important income source in Jamaica (Pienkowski *et al.* 2015). When the costs and benefits are unclear management conflicts can arise (Dickie *et al*. 2014). For example, *Acacia* species, a group of highly invasive non-native plants in South Africa, with concerning negative ecological impacts, also have economic importance as a source of timber (van Wilgen *et al.* 2011). The socio-economic impacts of INNP can be difficult to quantify as the data are not always easily available and many subjective measures such as impact on 'wellbeing' must be considered.

1.3 Research objectives

It is imperative that in this increasingly urbanising world we continue to further understanding of plant invasions in human-dominated landscapes in order to conserve biodiversity and functioning ecosystems for future generations. Despite invasion ecology being a rapidly expanding area of academic research with important and tangible applications (Richardson & Ricciardi 2013), key gaps remain. Several of these gaps are outlined below.

As previously mentioned, the social processes determining decisions made by individuals are of particular significance in domestic gardens, and furthermore, domestic gardens are one of the places where impacts of INNP can be most acute (Qvenlid *et al*. 2014). Despite this, research on the topic of the spread and impacts of INNP in domestic gardens is scarce compared with research on these topics at the landscape scale or for commercial sectors, e.g. agriculture (Qvenlid *et al.* 2014). It is important to consider the role humans have in spreading INNP in domestic gardens and the impacts of INNP therein as domestic gardens are one of commonest places many will encounter INNP. Given the high coverage of residential gardens in urban areas in many westernised countries (Gaston *et al.* 2005; Loram *et al.* 2007, Mathieu *et al.* 2007), it is important that gardens are managed correctly to maximize their contribution to biodiversity and in connecting fragmented landscapes (Davies *et al.* 2008). Domestic gardens can also provide multiple important well-being benefits (Freeman *et al.* 2012; Restall & Conrad 2015). These include (1) increased opportunities to engage with nature (Restall & Conrad 2015), (2) physical and mental health benefits (Freeman *et al.* 2012), and (3) opportunities to gain and share ecological knowledge (Barthel *et al*. 2010). In an increasingly urbanising world, domestic gardens are of paramount importance in mitigating reduced access and engagement with nature (Freeman *et al.* 2012). Better understanding of the social processes driving management of INNP in domestic gardens will help reduce their spread and impacts.

An individual's risk perception of a particular INNP is a strong determinant of their attitude towards it, which is a key determinant of their behavioural choices (Fischer & van der Wal 2007; Estévez *et al.* 2014). The research field of risk perception is growing, both in relation to environmental risks generally (Carlton & Jacobson 2013; Slimak & Thomas 2006) and, to a lesser degree, in relation to INNP (e.g. Fischer & Charnley 2012; Gozlan *et al.* 2013; Verbrugge *et al.* 2013; Estévez *et al.* 2014). Research regarding risk perception of INNP in domestic gardens however is scarce, and that which has been done has focused on distinctions between perceived invasiveness and status as native or non-native (e.g. Zagorski *et al.* 2004; Qvenlid *et al.* 2014). Research is needed on risk perceptions of the impacts INNP can have within domestic gardens. For example, how does perceived risk compare with the actual reality of the risks? What factors might be driving particular risk perceptions? Is the way INNP are discussed producing social amplification of risk? Greater understanding of the risk perceptions of those responsible for domestic gardens will help understand their management decisions with regards to INNP.

As humans play a significant role in the different stages of invasion, as discussed above, only by applying an interdisciplinary approach and combining methodological approaches from the natural and social sciences can we build a more comprehensive and complete picture of this problem. This thesis uses a diverse range of methods from each of these fields, including spatial modelling, content analysis, and structured and semi-structured interviews.

1.4 Japanese knotweed

Japanese knotweed *Fallopia japonica*, is used as a case study throughout this thesis. Japanese knotweed provides an excellent example for thinking about the various challenges of INNP in human-dominated landscape as it causes widespread ecological and economic damage typical of many INNP. Japanese knotweed, however, presents additional socio-economic challenges compared with other INNP that are discussed below.

Japanese knotweed is one of the best-known examples of an INNP as it is extremely widespread and problematic across much of North America and Europe, particularly in the UK (Figure 1.2; Barney *et al.* 2006). Japanese knotweed is an herbaceous rhizomatous perennial originating from Japan where it is an important pioneer species, especially at high altitudes following volcanic eruptions (Bailey *et al.* 2008). It can grow tall, up to 3m, and has small whitish flowers during the summer (Barney *et al.* 2006).

One of the first places Japanese knotweed was introduced into Europe was the Netherlands, where it won a gold medal in 1847 for being the 'most interesting new ornamental plant' (Bailey & Conolly 2000). There is debate over when Japanese knotweed first arrived in the UK, but the records of Kew Gardens, London, note that it arrived there on the 9th August 1850. Soon after it was available commercially (Bailey & Conolly 2000) and the first recorded escape from cultivation was in 1886 (Hollingsworth & Bailey 2000). Japanese knotweed was one of the more expensive plants at its time of introduction to the UK, because as well as being sought after for its ornamental value, it was prized for its supposed medicinal properties (Bailey & Conolly 2000).

Reproduction and spread of Japanese knotweed in the UK appears to have been entirely vegetative, as only one female clone is present (although there is evidence of hybridisation with similar species; see Bailey *et al.* 2008 for details). A notable feature of Japanese knotweed is its ability to regenerate from a small fragment of rhizome, some sources reporting regeneration from 0.7g to be possible (Sásik & Eliáš 2006; Colleran & Goodall 2014). Its roots make up about two thirds of its biomass, extending far both horizontally and vertically (Elghazouli 2010). These features of Japanese knotweed mean that humans can easily unknowingly spread it, for example through soil or garden discards (Barney *et al.* 2006).

Japanese knotweed has negative ecological impacts. By forming mono-specific stands it can significantly alter the physical environment, thereby directly outcompeting native species (Barney *et al.* 2006). It can also have subtler detrimental impacts for native plants, for example, via allelopathy it suppresses the growth of nearby plants (Dommanget *et al.* 2014). Its presence and spread can also have repercussions for other trophic levels (Barney *et al.* 2006). For example, through alterations to habitat it can be problematic for some animals (Palmer 1994). One study found that the biomass of the green frog *Rana clamitans* was reduced in areas of high Japanese knotweed abundance (Maerz *et al*. 2005).

Japanese knotweed can also have several socio-economic impacts. For example, (1) large expenses are incurred when controlling Japanese knotweed along riparian habitats, roads and railways, as in all these areas it can restrict access and reduce visibility (EA 2013; van Ham *et al*. 2013). (2) It can increase the risk of flooding by reducing the capacity of rivers to hold flood water (EA 2013). (3) Due to the dense monocultures it forms, Japanese knotweed is rarely perceived as aesthetically pleasing. One study estimated the cost of Japanese knotweed to the UK economy to be £165 million a year (Williams *et al.* 2010).

Perhaps the most acute socio-economic impacts of Japanese knotweed occur when the species is present on or nearby to domestic property. For example, (1) Japanese knotweed causes damage to hard surfaces by exploiting cracks in concrete, making it a concern for foundations of built structures, potentially leading to further expense (RICS 2012). (2) There have been cases where properties have been devalued or mortgages have been difficult to obtain when Japanese knotweed is on the property, or is nearby (Taylor *et al.* 2013; van Ham *et al.* 2013). (3) Spread between properties can escalate into disputes, sometimes resulting in legal action being taken (van Ham *et al*. 2013). These impacts are exacerbated by the fact that building insurance rarely covers damage caused by Japanese knotweed (RICS 2012). Many of these socio-economic impacts on domestic property appear at present specific to Japanese knotweed in the UK. As previously mentioned, the management of INNP in domestic gardens is dependent on the processes driving perceptions, attitudes and behavioural decisions, therefore it is important to explore these social processes to develop mitigation strategies to reduce their impacts and spread.

There are several pieces of legislation relevant to Japanese knotweed in the UK. The two most longstanding are the 'Wildlife and Countryside Act' (1981), under which it is an offence to plant or cause Japanese knotweed to spread in the wild, and the 'Environmental Protection Act' (1990), which regulates how Japanese knotweed can be disposed of (Bailey & Conolly 2000; Environment Agency 2006; Elghazouli 2010). Recently, two new pieces of legislation relating to Japanese knotweed have emerged. A reform of the 'Anti-social and Behaviour Act' in 2014 permits the act to be applied in circumstances where an individual or organisation is seen not to be controlling Japanese knotweed (or other problematic INNP) and the plant is having a detrimental effect of a 'persistent or continuing nature on the quality of life of those in the locality'. In this situation the local council or the police can issue a notice forcing the landowner to rectify the situation (Home Office 2014). In 2015 the 'Infrastructure Act' was introduced. Under this act environmental authorities (e.g. Natural England) have the authority to enforce landowners to enter into a 'species control agreement' to control Japanese knotweed or other INNP if it is deemed necessary. Failure to comply with either recently emerged piece of legislation can result in a fine, imprisonment, or both (House of Lords 2014). Awareness and understanding of such legislation is likely to influence how people manage Japanese knotweed in their gardens.

There are several options for controlling Japanese knotweed. The most common method is herbicides, either domestic or professional strength (Delbart *et al.* 2012). This approach however, is sometimes avoided due to concerns around the unwarranted impacts on nearby flora and fauna. An alternative is mechanical control. This approach also has disadvantages as it leaves behind the rhizomes and the waste material can be problematic to dispose of (Delbart *et al.* 2012). Usually a combination approach is best. However whichever method is chosen will require persistence and rarely leads to complete eradication (Manchester & Bullock 2000). Ultimately, the control option chosen will depend on human-dimensions, such as availability of financial resources, perceived extent of the infestation, perception of effectiveness of each approach and associated potential negative side effects of treatments. Ongoing research has identified a psyllid, *Aphalara itadori,* as a potential candidate for biological control (Shaw *et al.* 2011). After rigorous testing for undesirable effects on non-target vegetation in laboratory conditions, this approach is currently being tested in the field (Shaw *et al.* 2011; Clewley & Wright 2014).

The media have a keen interest in Japanese knotweed (Shaw *et al*. 2014). Much of this discourse has elements of fear and panic, which likely leads to the formation of strong opinions and attitudes towards the plant. Many individuals and organisations that are knowledgeable about Japanese knotweed have suggested that if it is dealt with sensibly and swiftly it need not cause excessive cost or anxiety (RICS 2012). Very little, however, is known about the details of the reality of this situation, the magnitude of the impacts of Japanese knotweed and the perception of the impacts amongst different stakeholders. Further knowledge of these topics is urgently needed to inform best practice management, awareness campaigns and policy.

All data within this thesis were collected in Cornwall, a county of ~3,500km^2 located in the south-west of the UK. Cornwall is an excellent study location as it is an area where Japanese knotweed is considered prevalent, and where there is a long history of research on it (Rennocks 2007). Furthermore, Cornwall is a hotspot for non-natives, as they comprised ~50% of the plant species in the county in 2015, compared with 10% nationally (Rudd 2016, unpublished).

1.5 Thesis structure

There are six data chapters in this thesis, each of which stands alone as a research paper. One is currently under-review with a peer-reviewed journal (chapter six) and two have been published (chapters four and five). The chapters are ordered according to the invasion processes outlined in this introduction and in Figure 1.1, starting with consideration of the spread of INNP in a human-dominated environment, then going on to consider the impacts.

Chapters two to six focus on the role played by humans in the spread of INNP. The first data chapter, chapter two, considers the relative influence of environmental and anthropogenic drivers on the presence and abundance of Japanese knotweed. This is the first study to combine environmental and anthropogenic drivers of INNP at the regional scale. Analysis at this scale has the greatest relevance for management recommendations that individuals can implement, in both private and public spaces.

Chapters three to six focus on the link between individual's knowledge, behaviour and decisions, and the spread of Japanese knotweed within and between domestic gardens. Chapter three considers a particular method by which humans move plants around: the movement of soil. For this chapter samples of soil from gardens and commercial housing developments were collected and kept under controlled conditions. Analysis considered the species richness and abundance of native, naturalised and invasive plants that germinated, between and within sources. If INNP are to be managed in gardens, they first need to be identified. Chapter four explores levels of plant identification skills amongst the public for both native and non-native species, including Japanese knotweed. It also explores what the levels of motivation for learning these skills are and how these skills are obtained. Once identified, to effectively manage INNP in gardens, those responsible need to be aware of the best management practices and understand the impacts they can have therein. Chapter five analyses variation in internet-based information sources regarding INNP to determine how this collective discourse might influence risk perceptions and management decisions for domestic garden owners/managers. Chapter six considers risk perceptions further and determines what the drivers of perceptions of risk of INNP in domestic gardens are.

Chapter seven considers the impacts of INNP on domestic property. In particular, it focuses on the magnitude and frequency of economic impacts INNP can have within domestic gardens as little research has been done on this topic, it then compares these with public perceptions on this topic. Chapters five to seven all consider how best to communicate the risks of INNP in domestic gardens, and balance the need to highlight the serious impacts INNP can have, against the need to avoid social amplification of risks and hyperbole.

The discussion chapter reviews and synthesises the contributions of this thesis to knowledge gaps regarding INNP in a human-dominated landscape and identifies research gaps remaining. The discussion refers back to the conceptual framework (Figure 1.1) and considers how this can be used to inform management, policy and awareness campaigns to reduce the spread and impacts of INNP. The discussion also considers the effectiveness of the interdisciplinary methods used to address the aims of this thesis.

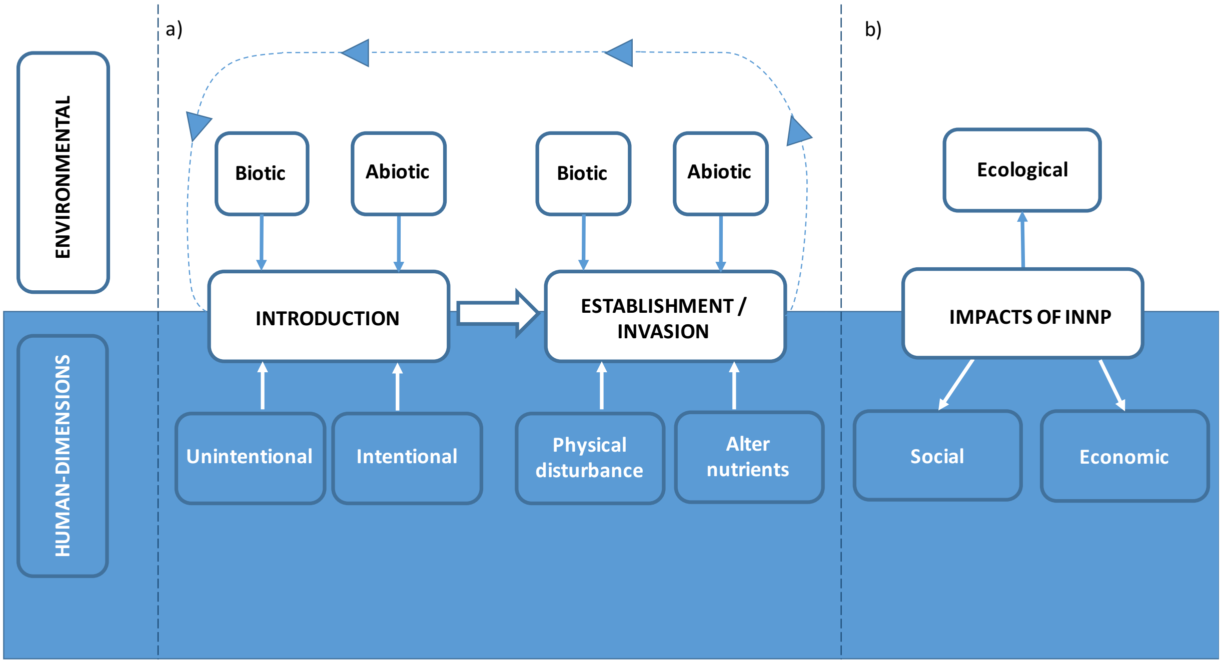

Figure 1.1 A conceptual framework for studying the spread and impacts of INNP in a human-dominated landscape.

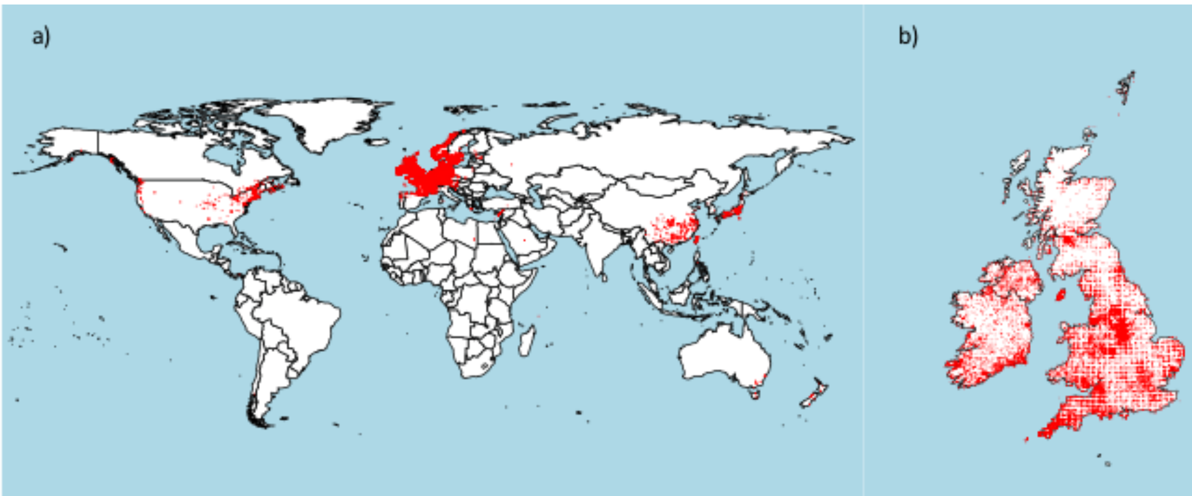

Figure 1.2 Current and historical distribution of Japanese knotweed a) globally and b) in the UK (data downloaded from GBIF 2016).

Chapter two

A fundamental first step in managing INNP, and therefore reducing their impacts, is to know where they are present and where they are most abundant. This allows for the most efficient allocation of finite resources. Biophysical variables are well-established drivers of presence and abundance of INNP. Likewise, increasing research has realised the importance of how the built environment influences vegetation characteristics. Far more recently, a handful of studies have found socio-economic variables, for example, socio-economic status of human populations, to be important in determining the presence and abundance of INNP. However, all studies done on this topic have been carried out on continental or country scales at a coarse scale. Chapter two explores the importance of these emerging socio-economic variables at a fine resolution ($1km^2$), and regional extent (Cornwall, UK), and compares this with the built environment (building density) and biophysical variables.

Chapter two:
Robinson BS, Early R, Inger R, Gaston KJ. Anthropogenic drivers of distribution and abundance of an invasive non-native plant.

Author contributions
I developed the idea for this chapter, collaborated with Cornwall Council to obtain the majority of the data, conducted the analyses, and wrote the manuscript.

Anthropogenic drivers of distribution and abundance of an invasive non-native plant

Abstract

To reduce the impacts of invasive non-native plants (INNP) we need to be able accurately to predict their current and future distributions. Traditionally, predictions of distributions have focused on using biophysical variables. Anthropogenic variables, particularly those concerning the built environment (e.g. building density), are increasingly being recognized as also important. However, INNP distributions and abundance could also be affected by geographic variation in human behaviour, motivations, and availability of financial resources. While direct quantitative data on these factors would be very hard to obtain, the influence of these factors could be captured by using socio-economic variables. Previous studies exploring the influence of socio-economic variables on INNP distribution and abundance have done so at continental and country extents at coarse spatial resolutions. However, results at a regional extent and fine resolution are needed in order to offer practical management advice, for example, where to focus monitoring and control of INNP to ensure efficient use of limited resources. It is therefore important we take advantage of the increasing availability of socio-economic data, and advances in the accuracy of spatial modelling techniques, to address this need.

In this study, we explore the relative importance of biophysical variables (average maximum and average minimum daily temperatures from the warmest/coldest months), the anthropogenic built environment (building density) and two socio-economic anthropogenic variables (the index of multiple deprivation – an index combining multiple measurements of deprivation - and housing tenure), at a fine resolution (1km^2) and regional extent (the county of Cornwall, UK), on the presence and abundance of INNP. We use Japanese knotweed *Fallopia japonica,* one of the most problematic INNP in Cornwall, as a case study.

We demonstrate that the most important variables predicting the presence and abundance of Japanese knotweed are building density, followed by minimum and maximum temperature (biophysical variables), then index of multiple deprivation, and

to a lesser extent proportion of socially rented properties (both socio-economic anthropogenic variables). These results have a number of implications for awareness campaigns, and priorities for management and investment in reducing the spread and impacts of INNP. For example, the lower likelihood of presence and abundance of Japanese knotweed in areas with a larger proportion of rented housing suggests that the authorities responsible for these properties - councils and housing associations - are increasingly aware of the problems Japanese knotweed can cause, and are therefore proactive in controlling it on the properties they manage. This suggests that 'top down' management from government authorities could be an effective way to reduce presence and abundance of INNP in these areas, perhaps in the form of grants for managing INNP to those on low incomes.

2.1 Introduction

One significant consequence of increasing globalisation and anthropogenic influence is the movement of plants around the globe (UN 2010; Banks *et al.* 2014). A subset of introduced plants become established, a further subset of which have serious ecological and socio-economic impacts (Simberloff *et al.* 2013; Kumschick *et al.* 2014). Predicting current and future distributions of invasive non-native plants (INNP) is critical to inform policy and management recommendations for reducing their spread and therefore their impacts (Václavík *et al.* 2012).

Predictions of INNP presence and abundance have traditionally focused on biophysical variables (Gallardo *et al*. 2015; González-Moreno *et al.* 2015). Biophysical variables often include average minimum temperature, average maximum temperature and altitude (Gallardo 2014; Gallardo *et al.* 2015). Biophysical variables can influence the survival rates of INNP at different stages of the invasion process by impacting mortality, reproduction and growth rates (Theoharides & Dukes 2007). Minimum temperature is often found to be the most important biophysical variable for a large variety of species (e.g. Gallardo & Aldridge 2013; Gallardo 2014; Gallardo e*t al.* 2015), and climate generally seems to have the greatest influence at global and continental scales (Thuiller *et al.* 2005; Casado *et al.* 2015).

Due to the role humans have in the transport and establishment of INNP (van Kleunen *et al.* 2015), attention is increasingly also being given to the effect of anthropogenic variables on INNP presence and abundance. This research is mostly focused on anthropogenic variables influencing the built environment, such as building density, road proximity and road cover (Houlahan *et al.* 2006; Gallardo *et al*. 2015; Szymura *et al.* 2016). These variables are obviously highest in urban areas, where conditions for invasive plants are often more favorable due to the heterogeneity of the environment, high levels of disturbance and multiple pathways for introductions (Francis & Chadwick 2015). These types of variables have frequently been found to be less important than biophysical variables in predicting the presence of INNP (Gallardo *et al.* 2015). Anthropogenic land use variables are also increasingly used to predict the presence and abundance of INNP (Lundgren *et al.* 2004; Lososova *et al.* 2006), with agriculture and ruderal habitats often found to have highest likelihood of presence and greatest abundance (Weber *et al.* 2008; González-Moreno *et al.* 2014). Whether habitat use or climate is more important in predicting invasive species appears to be scale dependent, with climate having a greater influence at large scales (Casado *et al*. 2015).

A small number of studies have found other anthropogenic variables such as socio-economic variation as potentially also being important at both country and continental scales. For example, one study found a positive relationship between the density of non-native plants and the Human Development Index (a composite index where a higher score represents a higher quality of life) in different European and North African Countries (Vilà & Pujadas 2001). Another study found that within the city of Tasmania, Australia, areas with a greater proportion of rented properties had a greater abundance of exotic shrubs in the gardens (Kirkpatrick *et al.* 2007). Socio-economic variation might be influencing presence and abundance of INNP via several mechanisms. 1) A greater coverage of brownfield sites and derelict land, which are often associated with greater deprivation (Doick *et al*. 2009), might provide suitable habitat for INNP (Lugo & González 2010). 2) Greater financial resource availability in different regions could mean more money that individuals or organisations can spend on INNP control (McDermott *et al.* 2013). 3) As different neighborhood norms are correlated with garden preferences, including preferences for native plants (Hope *et al.* 2003; Nassauer *et al.* 2009), neighbourhoods of different socio-economic status may vary in their tolerance of, or preference for, INNP. 4) Rented households may invest less in garden management, therefore, have a greater likelihood of INNP presence and abundance (Kirkpatrick *et al.* 2007). These types of variables can be captured in socio-economic variables that can be used to build models that predict presence / absence and abundance of INNP.

Studies exploring emerging socio-economic variables remain scarce. To our knowledge, no study has yet quantified the effects of socio-economic variables on INNP distribution and abundance nor established the relative importance of these variables compared with biophysical and built-environment variables, at a regional extent and at a fine scale resolution. Exploring these relationships at a regional extent and fine scale resolution is crucial for informing management recommendations to increase efficiency of monitoring and control efforts of INNP. Such management recommendations would be particularly useful in human-dominated environments which comprise a mosaic of private and public spaces managed by multiple individuals and organisations (Epanchin-Niell *et al*. 2010). Land cover in urban areas comprises a large proportion of domestic gardens, over 20% in some UK urban areas (Loram *et al*. 2007), the management of which might be highly influenced by the socioeconomic variables due to variations in the decisions, knowledge and motivations and financial resources of the individual(s) who own / manage them (Qvenild *et al.* 2014).

It is important we take advantage of the increasing availability of data on socio-economic variation at a fine scale spatial resolution, and advances in the accuracy of spatial modelling techniques to improve our knowledge about the relationship between INNP and socio-economic variables. In the UK the most complete measure of socio-economic status is the index of multiple deprivation. This index is a composite measure of 37 individual indicators grouped into seven distinct types of deprivation which are combined using varying weights to create an index scaling from 0 to 100, where a higher score indicates greater deprivation. An index of multiple deprivation is published every 3-5 years for each census output area (areas with an average population of 1,614 residents). Housing tenure data (whether people own, privately rent or socially rent properties) are also freely available and published every 3-5 years for each census output area in the UK.

Using *a priori* knowledge of possible mechanisms influencing occurrence and abundance of INNP at a fine spatial scale we ask the question: what is the relative importance of biophysical variables (average maximum and average minimum daily temperatures from the warmest/coldest months), the built environment (building density), and socio-economic anthropogenic variables (index of multiple deprivation and housing tenure) in influencing the presence and abundance of INNP at a regional extent and at a fine spatial resolution? We discuss possible mechanisms underlying the results of the models and the need for similar studies to consider socio-economic variables in the future.

As a case study we used Japanese knotweed *Fallopia japonica*, in Cornwall, a county of ~3,500km^2 in southwest England. This provides an excellent exemplar because (1) Japanese knotweed is a particularly problematic INNP in the region (Bailey & Conolly

2000), (2) it is often associated with urban areas with low socio-economic status (van Ham *et al*. 2013), and (3) detailed, unbiased distribution records are available for the region.

2.2. Methods

2.2.1 Response Variables

The majority of Japanese knotweed records (99.5%) were obtained from Cornwall County Council. These records were collected in a variety of ways, for example, from public observations and botanical groups, however, a significant amount (>90% polygon data) were collected by Cornwall Council employees. Cornwall Council has a long history of research and public engagement with Japanese knotweed and conduct surveys to identify it throughout the county in all habitat types. Therefore, we can be reasonably confident that the data are unbiased towards urban areas. The remaining data were obtained from the National Biodiversity Network (NBN 2015).

Data from 2000-2011 were extracted from both sources, in order to match the time-period of the explanatory variables as closely as possible. Duplicate records and points with spatial accuracy less than 100m were removed.

Data were supplied either as polygons encompassing the area covered by each stand of Japanese knotweed or as point localities of each stand. The resulting dataset consisted of more polygons (n = 4185 from Cornwall Council) than point locations (n = 3761 from Cornwall Council, n = 44 from NBN). Therefore, point locations were converted to polygons by drawing a circle centered on their coordinates that matched the mean size of existing polygons (area = 249.29m^2, radius = 8.91m), following Rodrigues *et al*. (2003). The presence/absence and abundance (percentage cover) of Japanese knotweed in each 1km^2 grid-cell was calculated using these polygons. To ensure robustness we also performed the analysis by converting polygons to point locations (see Appendix 2.1 for method and Table A2.1 for results). Land area of each grid-cell (m^2), after clipping to the Cornwall boundary, was included in the analysis as an explanatory variable. For comparison, analysis was also performed coding cells binomially as either inland or coastal/border instead of land area (see Table A2.2 for results).

2.2.2 Explanatory Variables

Biophysical variables were chosen based on Japanese knotweed's life history (Beerling *et al*. 1995) and included: average maximum daily temperature from the warmest month (maximum temperature) and average minimum daily temperature from the coldest month (minimum temperature). Sum of monthly average precipitation was omitted due to collinearity with other biophysical variables. The above climate variables were obtained at 5km resolution for the years 1981-2010 (Met Office 2015) and values were transferred to each 1km grid-cell that fell inside the 5km grid-cell. Coastal squares that did not overlap with climate data (3%, n = 116) were given the value of the nearest 5km grid-cell with data (the maximum distance climate data were transferred was 1km).

Building density was calculated as the percentage coverage of buildings within each 1km grid-cell (data from EDINA 2008 MasterMap Topography Layer). The 2010 index of multiple deprivation for census output areas in the study area was obtained for analysis (IMD 2010). Four types of household tenure data from 2011 (ONS 2011) were obtained (% of total properties), also for census output areas. Tenure types were i) properties owned (including those with mortgages and shared ownership); ii) total properties rented; iii) properties socially rented (with the council and private organisations); and iv) properties privately rented (through a private landlord or letting agency). All household tenure variables were checked for collinearity (Dormann *et al.* 2013). For pairs with correlation coefficients greater than 0.7 the variable with the strongest relationship to the response variable in a univariate model was retained. This process resulted in properties owned and total properties rented being removed. Data obtained for census output areas (index of multiple deprivation and housing tenure) were converted to a $1km^2$ grid by multiplying the proportion of the output area that overlapped with each 1km grid-cell by the original values, then summing for each 1km grid-cell, following Tratalos *et al.* (2008).

2.2.3 Statistical Analysis

Statistical analysis was conducted in R 3.1.3 (2015). To make the effects of explanatory variables easier to interpret they were standardized (Gelman 2008). To meet model assumptions, percentage building cover was log-transformed prior to use in the analysis. A hurdle model approach was used (Zuur *et al.* 2009). First, the effect that the explanatory variables had on presence/absence of Japanese knotweed was assessed using a generalised linear model with a binomial distribution. Second, the influence of explanatory variables on the abundance of Japanese knotweed (logit transformed) in grid-cells where it was present was assessed using a linear model (Williamson & Gaston 1999, Warton & Hui 2011).

Model averaging was carried out on all global models to calculate averaged parameter estimates and assess the relative importance of each parameter (using 'MuMIn' package; Barton *et al.* 2011). We followed the method from Gruber *et al.* (2011) and retained all models with ΔAIC<6 (Richards *et al*. 2008).

To account for spatial autocorrelation, we used the most supported method for each data type. For the presence/absence model the 'residual autocovariate' method developed by Crase *et al.* (2012) was applied. This approach estimates how much the residuals of the model that does not account for spatial autocorrelation are correlated with neighbouring cells. This correlation is termed the 'residual autocovariate' (RAC) and was calculated for each grid square by creating a 3 x 3 moving window using the 'raster' package (Hijmans 2015). The RAC is then included in the model as an additional explanatory variable. This method has been demonstrated to increase the predictive performance of models compared with more traditional approaches (Crase *et al.* 2012). The reliability of the RAC method has not been tested for abundance data. Therefore, for the abundance model we used a 'simultaneous autoregressive model error' approach, which models the spatial autocorrelation by assuming the spatial autocorrelation is in the error term. We used the simultaneous autoregressive approach as simulations have demonstrated that this is best at reducing spatially autocorrelation in species distribution data compared with similar approaches (Kissling & Carl 2008). Model residuals were tested for spatial autocorrelation using Moran's I and correlograms (using 'spdep' package; Bivand *et al.* 2015).

Model performance was assessed using R^2 (for global models containing all variables, method from Tjur (2009) for presence/absence models and Nagelkerke (1991) for abundance models) and AIC. Predictive power of presence/absence models was assessed by randomly partitioning data into training and testing datasets, containing 80% and 20% of the grid-cells respectively. The model built using training data was used to predict the testing data, and the area under ROC curve (AUC), sensitivity, and specificity of the predictions were calculated; this procedure was repeated ten times (Araújo *et al.* 2011).

2.3 Results

The final analysis included 3932 1km grid-cells, of which Japanese knotweed was present in 38.6% (n = 1517). Spatial models eliminated spatial autocorrelation and were the most parsimonious (Table 2.1), so were used for interpretation.

Japanese knotweed was more likely to be present in, and more abundant in, grid-cells with greater building cover, higher average minimum temperature and lower average maximum temperature, and higher index of multiple deprivation (in order of importance for presence/absence model; Table 2.1; see Table A2.3 for global model results). The index of multiple deprivation had a greater effect size in the abundance model than in the presence / absence model. All variables were retained in both the presence/absence and abundance averaged models. The proportion of socially rented properties was a significant negative predictor of the presence of Japanese knotweed, but was not significant in the abundance model. The proportion of privately rented properties was not significant in either the presence/absence or abundance model, though it was retained by model selection. The predictive power of the presence/absence model was good (AUC = 0.885 ± 0.004, sensitivity = 0.806 ± 0.014, specificity = 0.803 ± 0.011). Visual inspection supported a high degree of overlap between predicted and actual presence/absence (Figure 2.1), and similar patterns were observed in predicted and actual abundance (Figure 2.2).

2.4 Discussion

Despite the importance of socio-economic variables as predictors of presence and abundance of INNP at large spatial extents and coarse resolutions, no study has previously addressed this topic at a regional extent and at fine resolution. In this study we asked the question: what is the relative importance of biophysical variables, the built environment, and socio-economic anthropogenic variables in influencing the presence and abundance of INNP at a regional scale and fine spatial resolution? Results suggest that Japanese knotweed, a highly invasive and problematic plant in the study area, is more likely to be present in, and more abundant in, 1km grid-cells with greater building cover, higher average minimum temperature and lower average maximum temperature, and higher index of multiple deprivation (in order of importance).

Building density had the strongest influence on abundance of Japanese knotweed, in a positive direction, in both the presence/absence and the abundance model. A positive relationship has been found in many other studies exploring invasive plants and urbanisation measures (Pyšek 1998; McKinney 2001; Gallardo *et al.* 2015). The relationship is likely due to a combination of the characteristics of urban areas such as increased disturbance and frequent introductions via multiple pathways (Evans *et al.* 2005; Francis & Chadwick 2015). This finding suggests that if housing densities in the UK increase as planned (DETR 2000), INNP could become more abundant, and therefore more problematic. The variety of habitats and varying responsibilities for land management in urban areas makes managing INNP in these landscapes challenging. In particular, management of INNP in domestic gardens, which account for over 20% of land cover in some UK cities (Loram *et al.* 2007), are usually the responsibility of the owner / tenant of the property and can vary due to knowledge of those responsible for them (van Heezik *et al.* 2014). Recent research highlighted the variation in online management advice available for those responsible for managing INNP in domestic gardens, especially from local governments (Chapter 5). Therefore, effectively to manage INNP in urban areas it is critical that local governments invest more in disseminating consistent, detailed and practical advice on this topic.

The greater importance in our results of building density over biophysical variables, especially in the presence / absence model, contrasts with similar studies at larger scales (Gallardo 2014; Gallardo *et al*. 2015). This is perhaps due to less variation in the biophysical variables within the study area compared with larger scales. Previous research has found that the influence of climate on INNP varies depending on the scale being analysed, and has the greatest impact at larger scales (Casado *et al*. 2015).

Minimum temperature had the strongest effect of the two environmental variables explored; this is in accordance with similar studies exploring distributions of invasive plants (Gallardo 2014; Gallardo *et al.* 2015) as well non-invasive plants and even animals (Araújo *et al*. 2013), at larger scales. It is thought that the reason that cold temperatures have such a strong effect is because of the impact this has at the colonization and establishment stages of invasion (Theoharides & Dukes 2007; Gallardo 2014).

Our results also show that socio-economic variables can be important in predicting presence and abundance of INNP. Japanese knotweed is more likely to be present and in greater abundance in deprived areas – interestingly, this relationship was more important in the abundance than the presence / absence model. As the index of multiple deprivation is a composite variable, it is difficult to disentangle the causal mechanism of this relationship. As our results predicted that Japanese knotweed is more likely to be present in, and more abundant in both urban areas and areas with greater deprivation, the impact of INNP in deprived areas is likely to be multiplicative rather than additive. This suggests that deprivation status of individual(s) managing domestic gardens could be an important factor influencing the prevalence of INNP. One possible explanation for the relationship between socio-economic status and INNP therefore, might be that more disposable income is available in more affluent areas to control INNP in domestic gardens. Alternatively, in more affluent neighbourhoods there might be more pressure to conform to internalised social rules and keep gardens orderly (Nassauer *et al.* 2009). Data regarding socio-economic status are freely available in the UK at fine resolution, making incorporating them into studies exploring the distribution of other INNP relatively easy.

It is striking that Japanese knotweed presence and abundance was likely to be lower in areas with a larger proportion of rented housing. One might predict a higher presence and/or abundance of Japanese knotweed in social rented properties, because the transient nature of renters might result in less investment in garden management (Lerman & Warren 2011). However, we found the opposite. This may be because councils and housing associations are increasingly aware of the problems Japanese knotweed can cause, and are therefore proactive in controlling it on the properties they manage. This suggests that 'top down' management, in the form of intervention from government authorities, can be effective, particularly in deprived areas which our results suggest have greater likelihood of presence and abundance of Japanese knotweed. Perhaps a strategy similar to the grants provided for insulation to low income households in the UK that successfully reduced domestic energy loss (Wallace *et al.* 2010), could be used to provide assistance for those on low incomes to control INNP and reduce their prevalence in more deprived areas.

As anthropogenic pressures increase, consideration of both built environment variables and socio-economic variables in predictive modelling will give greater insight into processes underlying the distribution of INNP (Ramalho & Hobbs 2012). This in turn will increase the accuracy and utility of such predictions in informing policy and management guidelines, and in guiding decisions about where to focus INNP control and monitoring. To reduce the spread and impacts of INNP it is necessary to further understand the factors contributing to the relevant behaviours, motivations, and limitations underlying the socio-economic variation. Furthermore, our study was only possible due to the effort invested into local recording of INNP in the study region, highlighting the importance of investment in such recording.

Table 2.1 Results of analysis of presence/absence models and abundance of Japanese knotweed (standardised and model averaged) ordered by relative importance and then estimate. Moran's I and R^2 are from the global model, AIC is from the averaged model.

	Without accounting for spatial autocorrelation		**Accounting for spatial autocorrelation**	
	Estimate ± standard error	Relative importance	Estimate ± standard error	Relative importance
PRESENCE / ABSENCE MODEL	**Moran's I = 0.180, p<0.001 R^2 = 0.216, AIC = 4314.7**		**Moran's I = -0.130, p = 1 R^2 = 0.463, AIC = 3139.1**	
Building cover (logged)	2.834 ± 0.144 ***	1.00	2.499 ± 0.162 ***	1.00
Land area	0.929 ± 0.125 ***	1.00	1.139 ± 0.145 ***	1.00
Minimum temperature	0.527 ± 0.086 ***	1.00	0.594 ± 0.102 ***	1.00
Maximum temperature	-0.500 ± 0.084 ***	1.00	-0.367 ± 0.099 ***	1.00
Percentage of properties socially rented	-0.440 ± 0.079 ***	1.00	-0.323 ± 0.096 ***	1.00
Index of Multiple Deprivation	0.399 ± 0.085 ***	1.00	0.314 ± 0.104 **	1.00
Percentage of properties privately rented	-0.188 ± 0.079 *	0.87	-0.114 ± 0.096	0.43
Residual autocovariate	- -	-	2.931 ± 0.106 ***	1.00
ABUNDANCE MODEL	**Moran's I = 0.223, p<0.001 AIC = 5019.9, R^2 = 0.094**		**Moran's I = -0.009, p = 0.700 AIC = 4937.8, R^2 = 0.144**	
Building cover (logged)	0.939 ± 0.107 ***	1.00	0.828 ± 0.111 ***	1.00
Index of Multiple Deprivation	0.460 ± 0.082 ***	1.00	0.376 ± 0.089 ***	1.00
Minimum temperature	0.231 ± 0.072 **	1.00	0.238 ± 0.092 **	0.94
Maximum temperature	-0.174 ± 0.073 *	0.88	-0.198 ± 0.090 *	0.81
Percentage of properties socially rented	-0.146 ± 0.067 *	0.81	-0.100 ± 0.077	0.46
Percentage of properties privately rented	-0.065 ± 0.070	0.36	-0.050 ± 0.081	0.29
Lambda	- -	-	0.288 ± 0.030 ***	-

Significance codes: 0 = '***'; 0.001 = '**'; 0.01 = '*'; ns = ' '.

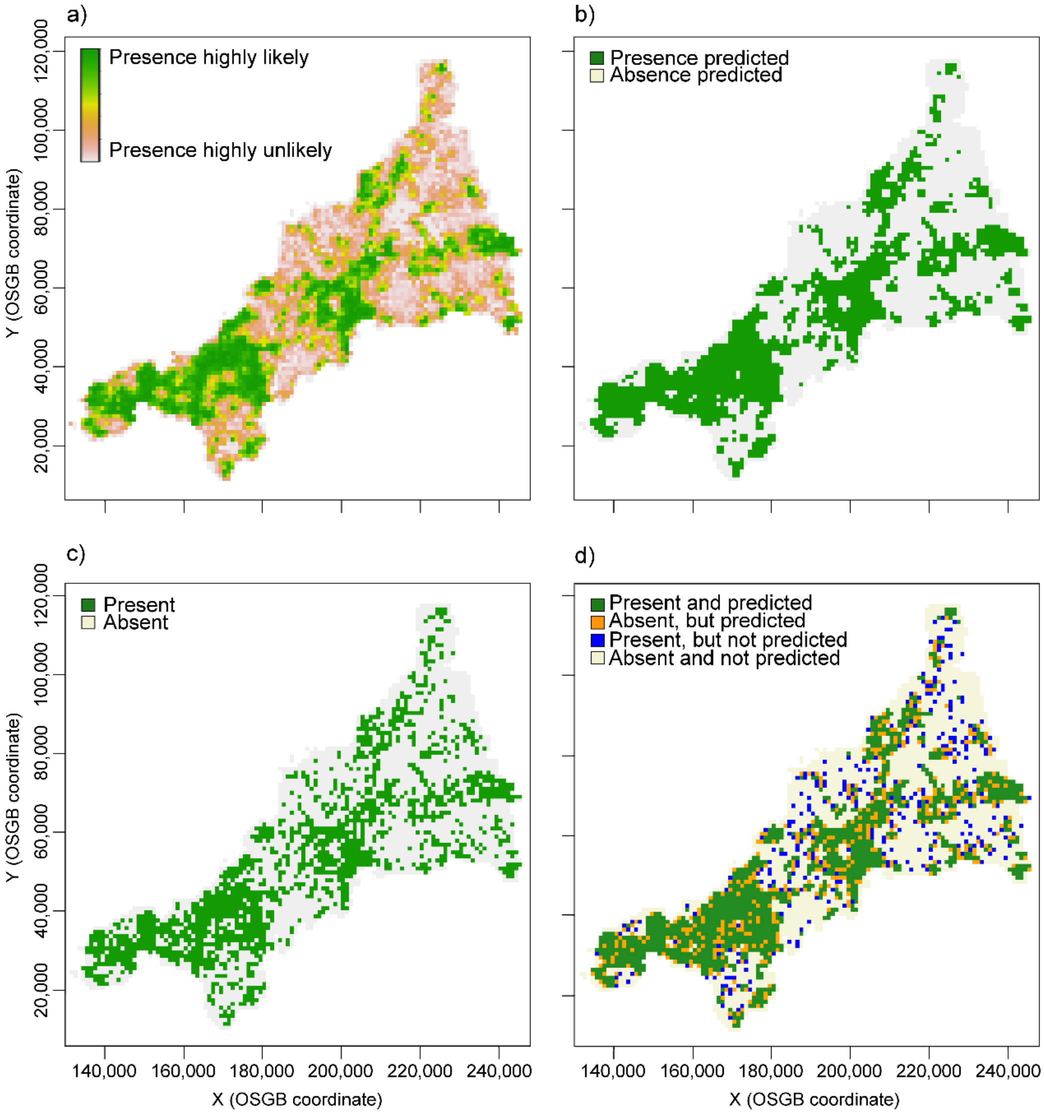

Figure 2.1 1km^2 distribution maps of Japanese knotweed of a) predicted likelihood of presence (continuous); b) binary predicted likelihood of presence (threshold derived using 'SDMTools' package; van Der Wal *et al*. 2014); c) actual presence/absence; and d) lag map showing discrepancies between predicted and actual presence/absence (produced using all data).

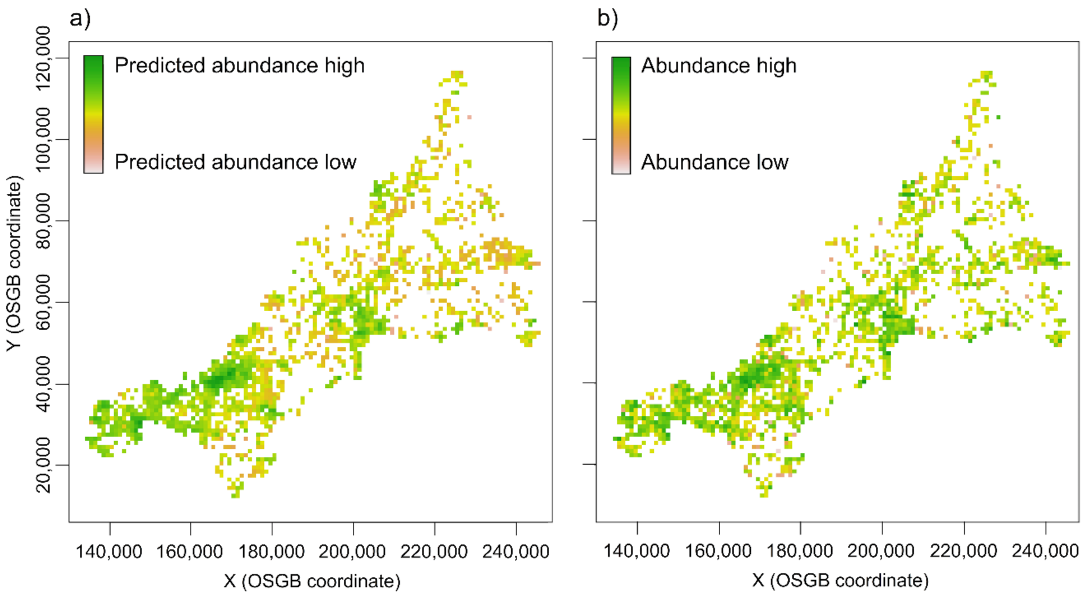

Figure 2.2 Abundance maps of a) predicted and, b) actual coverage of Japanese knotweed per 1km^2 (logit transformed).

Chapter three

A key finding from chapter two is that building density is the strongest predictor of presence and abundance of Japanese knotweed. This suggests that Japanese knotweed is most abundant in urban areas. As domestic gardens comprise a large percentage of urban areas, they are therefore a key focus of the remaining chapters in this thesis. Another key finding of chapter two is that emerging anthropogenic social-economic processes also have an important role in determining presence and abundance of Japanese knotweed. One social process within gardens that might be spreading INNP that has received little research attention is the movement of soil between gardens. Chapter three determines the quantities and invasive status of plants moved via soil between gardens and compares it with soil from commercial housing developments. The results of this chapter are important for informing policy and management to reduce the spread of invasive plants.

Chapter 3:
Robinson BS, Bennie J, Inger R, Early R, Gaston KJ. Sweet flowers are slow and weeds make haste: anthropogenic dispersal of plants via soil.
This chapter has been written for Biology Letters.

Author contributions
I developed the idea for this chapter, collected the soil samples, propagated the plants, J. Bennie and I identified the plants, I conducted the analyses, and wrote the manuscript.

Sweet flowers are slow and weeds make haste: anthropogenic dispersal of plants via soil

Abstract

Anthropogenic activities are increasingly responsible for the dispersal of plants. Of particular concern is anthropogenic dispersal of problematic invasive non-native plants. A common dispersal vector is the movement of soil containing seeds or rhizomes. Housing development and domestic gardening activities cause large quantities of soil to be moved, and understanding the role of these activities is critical for informing policy and management to reduce the spread of problematic plants. Here, by collecting soil samples being moved for housing development and domestic gardening and observing the species that germinated from these samples, we determined the quantities and invasive status of plants moved. From our samples nearly 2000 individuals representing 90 species germinated. Our results suggest that given the quantity of topsoil needed to cover an average sized UK garden ($190m^2$) there could be 2.2 million and c.2 million viable seeds in soil sourced from housing developments and domestic gardens respectively. In both housing development and garden samples, native species were more abundant and species rich than non-native naturalised and invasive species. Buddleia (an invasive species) was the most common species overall and in garden samples; this is likely due to multiple traits that adapt Buddleia to dispersal. The abundance of invasive and naturalised species was significantly higher in garden than in housing development samples, suggesting that informal movement of soil between gardens poses a greater risk of spreading invasive plants than commercial sources. The consequences for models predicting future distributions of plants, and strategies to mitigate anthropogenic dispersal of problematic plants are considered.

3.1 Introduction

Anthropogenic dispersal, both intentional and unintentional, has long been a factor in determining plant distributions (Thuiller *et al*. 2006). However, the magnitude and impacts of anthropogenic dispersal are increasing at an unprecedented rate due to growth in global trade and travel (Banks *et al.* 2014). Anthropogenic activities can move plants within and beyond their native ranges. Some species moved in this way will become invaders with serious ecological and socio-economic impacts (Simberloff *et al.* 2013).

One of the most important anthropogenic dispersal pathways is the transport of seeds or rhizomes within soil (Hodkinson & Thompson 1997; Hulme *et al.* 2008). For example, an average of 5.4 seedlings germinated from commercial topsoil samples ($120cm^3$) from an arable source in Northern England (Hodkinson & Thompson 1997). Transportation of invasive non-native plants (INNP) via soil is particularly concerning, given that many INNP are already capable of high rates of dispersal into disturbed habitat, for example, by prolific seed production (e.g. Buddleia *Buddleia davidii;* Kriticos *et al.* 2011), or re-growth from small rhizome fragments (e.g. Japanese knotweed *Fallopia japonica*; van Ham *et al*. 2013).

Two of the main activities by which soil is trans-located are (1) to and from construction sites and (2) between domestic gardens. One study estimated that 0.8 gigatons of earth (soil and rock) is moved annually due to house building in the US (Hooke 1994); this is likely to increase as global demand for new houses grows. The UK government, for example, plans to build 1 million new homes before 2020 (Prime Minister’s Office 2015). Estimating the quantity of soil moved between domestic gardens is difficult but important. In the UK, where ownership of domestic gardens exceeds 20 million and gardening is the country’s most popular leisure activity (67% of UK adults list gardening as a hobby (Gross & Lane 2007), the amount of soil transported for gardens is likely to be significant. Traditionally, garden soil was likely obtained from known sources such as friends and family. However, soil is increasingly obtained from a greater variety of sources using ‘informal networks’, for example, internet trading sites (e.g. Freecycle™ and Gumtree™) and newspaper adverts.

Despite large quantities of soil being frequently moved due to house construction and gardening, to our knowledge, no research has empirically studied which species are transported via these methods and in what quantities. Such research is critical for informing policy and management guidelines to reduce the spread of problematic species via such transportation routes. Furthermore, the accuracy of models to predict future distributions of INNP could be greatly improved by better understanding of their anthropogenic dispersal mechanisms. Predicting these distributions is key for identifying high risk areas, and subsequently to inform management recommendations (Hodkinson & Thompson 1997; Gallardo *et al.* 2015).

In this study we determined the species, invasive status and abundance of plants transported in samples of soil a) used on housing developments and b) being swapped between gardens via 'informal networks' in the UK. We explored relationships between status (native, naturalised and invasive) and a) plant abundance, and b) species richness.

3.2 Method

Soil samples were collected throughout west Cornwall, UK from a) commercial residential housing developments (n = 15), which were at different development stages, from land-clearing through to selling properties; and b) soil being moved between gardens using 'informal networks' (n = 15; see Appendix 3.1 for details). We offered and provided no incentive for samples.

Following piloting studies, data collection began in March 2015. We took 10 samples of $200cm^3$ of soil from a range of depths and locations within each site or mound of soil. Samples were kept under controlled conditions to encourage germination (see Appendix 3.2 for details). Most plants were identified between 6 and 12 weeks, though any that could not be identified at this stage were grown on until this was possible. Plants were identified to the highest taxonomic level possible, scientific names checked (www.theplantlist.org), and perennation (annual, biennial, perennial) and native status (native, naturalised or invasive) recorded (Hill *et al.* 2004; Appendix 3.3 for details). The number of viable seeds in the amount of topsoil needed to cover an average sized UK garden was calculated (see Appendix 3.4 for calculations).

Analyses were performed using R 3.1.3 (R 2015). Unidentified plants were excluded from statistical analysis. Using a GLMM (Poisson distribution) the 'abundance model' explored the effects of the explanatory variables 'source' (housing development or garden), 'native status' and 'perennation' on plant abundance (number of individual plants per sample). Species was included as a random effect. To account for over-dispersion, an observation level random effect was included, as this has been demonstrated to reduce over-dispersion of the type we observed (Harrison 2014). Using a GLM (Poisson distribution), the 'species richness model' explored the relationship between the explanatory variable 'native status' on the dependent variable of 'species richness' (number of species per sample). It was not possible to include perennation in the species richness model because within the samples were species with multiple perennation strategies. Models were evaluated using R^2 values (using method from Nakagawa & Schielzeth 2013) and AIC.

3.3 Results

When data for garden and housing samples were pooled, 1828 individual plants of 90 different species germinated, of which 80 species (1817 individuals) were identifiable (see Table A3.1 and Appendix 3.5 for details). When scaled up, this suggests that in the topsoil needed to cover an averaged sized garden of 190m^2, soil sourced from housing developments and gardens contains 2,184,354 (95% CI = 1,456,106, 3,028,683) and 1,983,600 (95% CI = 856,039, 3,310,717) viable seeds respectively.

In housing market samples, 91.7% (n = 878) of individuals were native, 1.5% (n = 14) naturalized, 6.5% (n = 62) invasive and 0.4% (n = 4) were unidentified. In garden samples, 63.3% (n = 551) of individuals were native, 7.9% (n = 69) naturalized, 27.9% (n = 243) invasive and 0.1% (n = 7) were unidentified. Buddleia, a non-native, comprised the largest proportion of species in all samples (13.9%, n = 254) and in garden samples (25.7%, n = 224). There was large variation in the abundance of individuals in each sample, particularly within native species (Figure 3.1). Native species were most species rich, followed by naturalised, then invasive species (Figure 3.1 and Figure 3.2; Table A3.2).

Abundance model

Including perennation in the abundance model did not improve parsimony (assessed using AIC), and it was therefore omitted. Species abundance was not significantly different between sources, or between invasive and native plants. However, naturalised species were significantly less abundant than native species overall, and both invasive and naturalised species were more abundant in garden samples than in housing development samples (Table 3.1a; Figure 3.1a). Invasive species were more abundant than naturalised, however, this relationship was not statistically significant (Tukey's HSD test: z-value = -1.44, p = 0.312) and was driven by the high abundance of buddleia.

Species richness model

Garden samples had significantly lower species richness than housing development samples, and both naturalised and invasive plants had significantly lower species richness than native plants (Table 3.1b; Figure 3.1b).

3.4 Discussion

Results of this study demonstrate for the first time that large numbers of several native, naturalised and invasive plants are being dispersed in soil moved from, to and between housing development sites and gardens. The number of plants that germinated from our samples totaled nearly 2000 individuals of 90 species. When scaled up, this suggests that given the quantity of topsoil needed to cover an average sized UK garden there could be 2.2 million and c.2 million viable seeds in soil sourced from housing developments and domestic gardens respectively.

The predominance of Buddleia in our samples was unsurprising considering its possession of multiple traits typical of invasive species: prolific seed production, fast growth, brief juvenile phase and small seeds (Tallent-Halsell & Watt 2009; Kriticos *et al.* 2011). The last trait is particularly important for transportation within soil. Conversely, Japanese knotweed, a particularly problematic INNP in the UK, was absent in our samples. This is surprising, as Japanese knotweed is considered widespread in the study area and possesses traits adapted to transportation within soil (van Ham *et al.* 2013), and as concerns about Japanese knotweed spreading via soil are voiced repeatedly (Bailey 2011; van Ham *et al*. 2013).

Given that the abundance of invasive and naturalised species was significantly higher in soil sourced from domestic gardens than from housing developments, informal movement of soil between gardens is more likely to spread INNP than is the construction industry. It should be noted that many naturalised species not currently classified as problematic may become so in the future, particularly if their abundance and range is expanded by anthropogenic transportation (Simberloff *et al*. 2013). In addition to having negative ecological and socio-economic impacts within gardens, INNP species spread via soil might also escape into the wider environment and cause further damage (Dehnen-Schmutz *et al*. 2007b).

In the UK, regulations and guidelines influence how housing developers move, store, process and dispose of soil (DEFRA 2009; Government Environmental Permits 2016), and commercial topsoil has to comply with rigorous standards (BSI 2015). Soil moved between gardens is not subject to such restrictions. Expanding the regulation to which developers must adhere when moving soil to include soil transferred between domestic gardens would be extremely difficult to implement and monitor. Therefore, developing incentives for voluntary regulation, such as encouraging recycling soil on site, should be a priority. Furthermore, promoting awareness among domestic garden owners / managers, of the need to monitor imported soil for INNPs which may inadvertently have been introduced, will help in early identification and allow more effective control (Simberloff *et al.* 2013).

In conclusion this study demonstrates new evidence of the scale of anthropogenic plant dispersal. Greater consideration of anthropogenic plant dispersal via soil in models forecasting species range shifts, alongside awareness campaigns to highlight the hazards of moving soil around and the need to monitor what grows from such soil, could mitigate the negative implications of anthropogenic plant dispersal.

Table 3.1 Results of models exploring a) species abundance and b) species richness. Base categories were housing development and native.

	Parameter Estimate	Standard Error	z-value	Significance
a) Effect of source and status on plant abundance **R^2 marginal = 0.041; R^2 conditional = 0.114**				
Intercept	1.02	0.11	9.17	***
Source (garden)	-0.17	0.15	-1.19	NS
Native status (invasive)	-0.31	0.34	-0.9	NS
Native status (naturalised)	-1.08	0.44	-2.46	*
Source (garden) x native status (invasive)	0.88	0.41	2.17	*
Source (garden) x native status (naturalised)	1.45	0.56	2.57	*
b) Effect of source and status on species richness **R^2 = 0.098**				
Intercept	2.43	0.08	31.65	***
Source (garden)	-0.39	0.12	-3.19	**
Native status (invasive)	-1.99	0.25	-7.83	***
Native status (naturalised)	-2.11	0.31	-6.78	***
Source (garden) x native status (invasive)	0.42	0.36	1.18	NS
Source (garden) x native status (naturalised)	0.39	0.44	0.89	NS

Significance codes: < 0.001 '***', < 0.01 '**', < 0.05 '*', NS = non-significant.

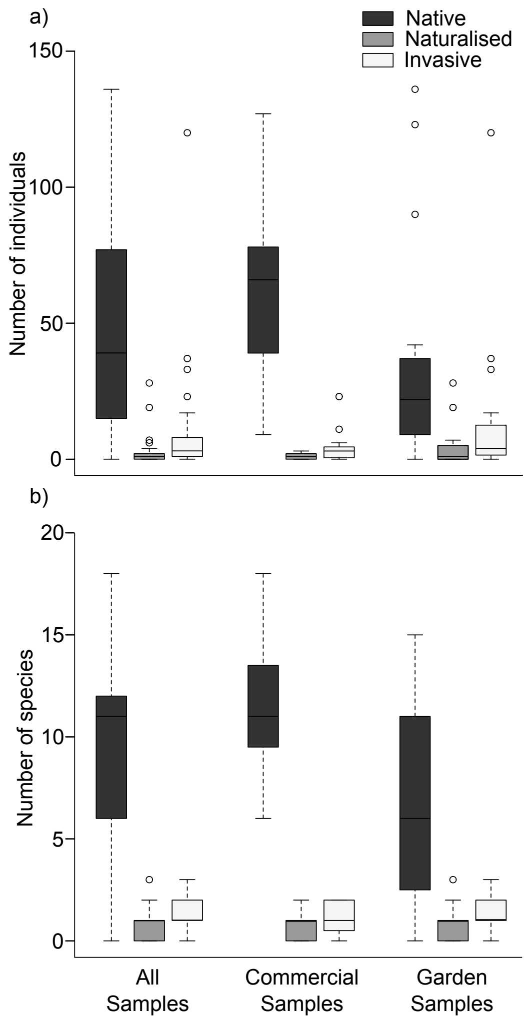

Figure 3.1 Box and whisker plots for the number of a) individual plants and b) species per sample, categorized by source and status.

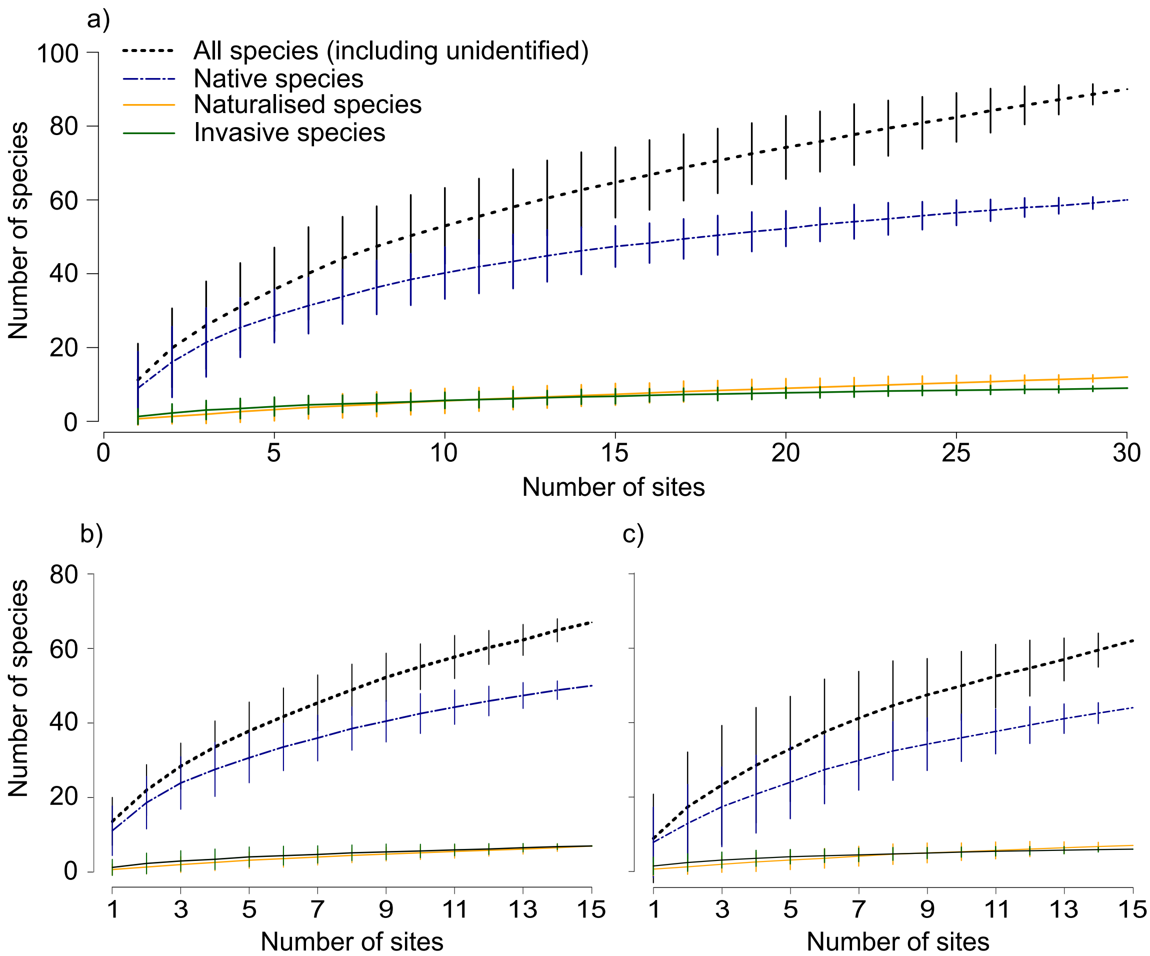

Figure 3.2 Species accumulation curves for a) all samples, b) housing development samples and c) garden samples, by species status.

Chapter four

A key point raised in chapter three is that to reduce the spread of INNP via soil it helps if people can recognise them. This is particularly true of domestic gardens, as given their semi-private nature many gardens, back gardens in particular, are largely observed only by those responsible for them. If those responsible for the garden cannot recognise INNP, it increases the likelihood that the plant will spread further and have greater ecological and socio-economic impacts. The ability to recognise INNP in the wider environment also has benefits, as it increases the ways the public can contribute to citizen science projects to monitor them. Despite the benefits that the ability to identify INNP can bring, no study has explored what levels of identification abilities exist amongst the public. Chapter four explores levels of identification of INNP, as well as less problematic non-native plants and native plants, and determines socio-demographic predictors of this knowledge. Results of this chapter can help with design and targeting of awareness and educational campaigns in the sections of society where knowledge is low.

Chapter 4:
Robinson B, Inger R, Gaston KJ (2016) A Rose by Any Other Name: plant identification knowledge & socio-demographics. PLoS One, 11(5), e0156572.

Author contributions
I had major input towards the idea for this chapter, I designed the survey, collected survey responses, conducted the analyses, and wrote the manuscript.

A Rose by Any Other Name: plant identification knowledge & socio-demographics

Abstract

Concern has been expressed over societal losses of plant species identification skills. These losses have potential implications for engagement with conservation issues, gaining human wellbeing benefits from biodiversity (such as those resulting from nature-based recreational activities), and early warning of the spread of problematic species. However, understanding of the prevailing level of species identification skills, and of its key drivers, remains poor. Here, we explore socio-demographic factors influencing plant identification knowledge and ability to classify plants as native or non-native, employing a novel method of using real physical plants, rather than photographs or illustrations. We conducted face-to-face surveys at three different sites chosen to capture respondents with a range of socio-demographic circumstances, in Cornwall, UK. We found that survey participants correctly identified c.60% of common plant species, were significantly worse at naming non-native than native plants, and that less than 20% of people recognised Japanese knotweed *Fallopia japonica*, which is a widespread high profile invasive non-native in the study region. Success at naming plants was higher if participants were female, a member of at least one environmental, conservation or gardening organisation, in an older age group (than the base category of 18-29 years), or a resident (rather than visitor) of the study area. Understanding patterns of variation in plant identification knowledge can inform the development of education and engagement strategies, for example, by targeting sectors of society where knowledge is lowest. Furthermore, greater understanding of general levels of identification of problematic invasive non-native plants can guide awareness and education campaigns to mitigate their impacts.

4.1 Introduction

People are losing familiarity with the natural world, particularly in western countries, potentially resulting in a loss of ecological knowledge (Pilgrim *et al.* 2008), including the ability to identify even the most common species, as well as those of cultural significance (Miller 2005; Pilgrim *et al.* 2008; Stagg & Donkin 2013). This loss of familiarity and knowledge is cause for profound concern as it may lead to reduced appreciation of the natural world (Pyle 2003; Miller 2005; Stokes 2006), reduced motivation to protect species (Pyle 2003), less willingness to support nature conservation organisations (Pyle 2003), and perhaps a reduced ability to gain associated human wellbeing benefits, such as those resulting from nature-based recreational activities (e.g. bird watching; Dallimer *et al.* 2012). Furthermore, poor identification skills may contribute to a reduced ability or willingness to engage in documenting and monitoring biodiversity. This includes the tracking of the spread of problematic invasive non-native species, where early identification can facilitate more successful and cost effective management actions (Dallimer *et al.* 2012; Dermott *et al.* 2013; Simberloff *et al.* 2013).

A handful of studies have examined societal knowledge of species identification, finding mixed results. For example, one investigation found Slovakian elementary school children (aged 10-15) and university students were able to identify 30-48% of common bird species (Prokop & Rodak 2009), another that children aged 4-12 in Scotland, UK were able to identify 56, 43 and 44% of arthropod, bird and mammal species respectively (out of 40 species randomly drawn from 68; Huxham *et al.* 2006), and a third that children were better able to identify artificial Pokémon characters than common native wildlife (Balmford *et al.* 2011). However, empirical evaluations of people's identification skills are scarce and this is particularly true for plant species. Despite having the advantage of being immobile, relatively well described and provisioned with field guides (at least in most Western countries), plants have the disadvantage of lacking the charisma of many bird and mammal species, are significantly more diverse, are often morphologically different between seasons and life-stages, and are widely regarded as difficult to identify (Wandersee & Schussler 1999; Schussler & Olzak 2008; Stagg & Donkin 2013). Those studies that have been conducted have typically found low levels of plant identification skills (Bebbington 2005; Gatt *et al.* 2007;

Dallimer *et al.* 2012; Stagg & Donkin 2013, Woodland Trust 2013). For example, visitors to urban greenspaces in the UK could on average correctly identify only one out of four plant species common to that area (Dallimer *et al.* 2012), and only 10% of 18-24 years olds in the UK could correctly identify ash *Fraxinus excelsior*, one of the most common tree species in that region (Woodland Trust 2013). This said, some studies have found higher levels of identification of common plant species, for instance 70% of participants in one analysis correctly identified buttercup *Ranunculus spp.* (Pilgrim *et al.* 2008). Studies exploring identification skills of invasive non-native species are even scarcer than those of natives. A study of the Australian public found a 20.5% error rate when distinguishing native frogs from the harmful invasive non-native cane toad *Bufo marinus* (Somaweera *et al.* 2010). To our knowledge, however, no study has examined people's ability to identify problematic invasive non-native plants.

Studies examining identification skills have tended to focus on particular sectors of society (e.g. students; Bebbington 2005), plants associated with particular locations (e.g. Dallimer *et al.* 2012) and, with one notable exception (Stagg & Donkin 2013), most have used photographs or illustrations of species. Although several socio-demographic variables have been identified as important in predicting plant identification skills, including age (Bebbington 2005; Pilgrim *et al.* 2008; Woodland Trust 2013), gender (Wandersee & Schussler 1999; Gatt *et al.* 2007) and level of education (Stagg & Donkin 2013), their relative importance has seldom been explored. Greater understanding of socio-demographic factors influencing plant identification skills could assist with targeting awareness and educational campaigns in sections of society where knowledge is low.

In this study we ask three questions. First, which socio-demographic factors influence people's ability to name common plants and their ability to classify plants as native or non-native? Second, how is plant identification knowledge obtained? Third, what are levels of support and motivation for learning plant identification skills? To achieve this we surveyed people with a range of socio-demographic circumstances and used real plant specimens to test identification skills.

4.2 Methods

4.2.1 Survey design

The surveys were conducted at three sites in the town of Falmouth, Cornwall, UK, during August 2013. These were chosen to capture a cross-section of society and comprised two beachside locations and one town centre location, with the goal of engaging as a wide a range of people (over 18 years of age, and UK residents) as possible. Each site was visited an equal number of times and participants were selected at random. The surveys (total n = 220) were delivered face-to-face, with one participant at a time, and were completed on site. For consistency, it was delivered by the same individual (first author, BR) in all cases. The survey comprised 14 questions (see Table A4.1), and was piloted several times before being formally administered to refine the method and wording of the questions, following guidance from Bernard (2011).

First, participants were asked to identify samples of real plants, using a mix of fresh cuttings and potted plants purchased from a local garden centre. Using real plants, rather than images, allows the participants to gain a better idea of smell, size and texture of the plants. The plants used comprised six natives: Lavender (*Lavandula angustifolia),* Rose spp. (Genus: *Rosa*), Common Heather (*Calluna vulgaris*), Blackberry (*Rubus fructicosus*), Ivy (*Hedera helix*) and Bracken (*Pteridium aquilinum*); and six non-natives: Hydrangea spp. (Genus: *Hydrangea*), Fuchsia spp. (Genus: *Fuchsia*), Montbretia (Genus: *Crocosmia*), Red valerian (*Centranthus ruber*), Buddleia (*Buddleja davidii*), and Japanese knotweed (*Fallopia japonica).* This set of species was determined following consultation with experts with specialist knowledge on gardening and ecology (n = 8); these included ecological consultants, academics and garden centre employees. Each expert was asked to provide a list of 12 plants, six native and six non-native, that were relatively easy to identify, common in UK domestic gardens, and medium sized. Plants were considered non-native if they first occurred in Britain after AD 1500 (Maskell *et al.* 2006). Experts were asked to include native and non-native plants that are actively planted and frequently valued, as well as native and non-native plants that grow wild in gardens without assistance, and plants sometimes considered a nuisance (although this is subjective and some plants fit both criteria). The authors combined these lists with literature - both academic and non-academic - on common UK plants and their flowering times (e.g. RHS 2015; Streeter *et al.* 2010) to select the final 12 plants. The majority of plants were flowering at the time the survey was conducted. Japanese knotweed was chosen as an example of a problematic invasive non-native plant as it is considered one of the most ecologically and economically damaging invasive non-native plants in the UK, where it is widespread in a variety of habitats (Engler *et al.* 2012; Gozlan *et al.* 2013). In 2010 Japanese knotweed was estimated to have cost the UK economy £165 million (Williams *et al*. 2010). After giving a broad definition of 'non-native species' and revealing the plant names, participants were asked whether the plants (or close relatives of) were native or non-native.

The second section of the survey presented participants with statements regarding their attitudes towards plant identification, such as whether the individual thought it was an important skill to have, as well as if and how they learned their plant identification skills, and whether or not they were motivated to learn more. These questions were assessed using a five point Likert scale of 'strongly disagree', 'disagree', 'neutral', 'agree', or 'strongly agree' (Bernard 2011). The second section also included questions addressing how much participants had been taught plant identification skills in the past and how these skills were obtained. The final section obtained data on socio-demographics (age category; gender; education level; membership of environmental, conservation or gardening organisations; garden ownership; and if participants were resident in Cornwall or elsewhere in the UK). The socio-demographic variables were chosen based on factors found to be important in explaining ecological knowledge from case studies within the academic literature (e.g. Bebbington 2005; Huxham *et al.* 2006; Pilgrim *et al.* 2008; Stagg & Donkin 2013; Woodland Trust 2013).

The sample comprised a higher percentage of women (58.2%, n = 128) than national and Cornwall averages (50.8% and 51.6% respectively; (ONS 2011), Table 4.1). It comprised a similar percentage in the 18-29 age category as national and Cornwall averages (17.3%, 20.6% and 20.7% respectively); a smaller percentage in the 30-39 age category (8.6%, 16.8% and 16.9 % respectively); a larger percentage in both the 40-49 age category (25%, 18.6% and 18.6% respectively) and the 50-59 age category (22.7%, 15.4%, 15.4% respectively); and a similar percentage in the 60+ age category (26.3%, 28.6% and 28.5% respectively (ONS 2011).

4.2.2 Statistical analysis

All analyses were carried out in R (3.0.3; 2013). No collinearity was found between explanatory variables (assessed using Pearson's correlation coefficient with cut-off <0.8; Dormann *et al.* 2013). Generalised linear mixed effect models (using the 'lme4' package; Bates *et al*. 2014) with a binomial error structure were constructed to explore the effect of socio-demographic factors selected *a priori* (age; gender; education; membership of environmental, conservation or gardening organisations; garden ownership; and if participants were resident in Cornwall or elsewhere in the UK – all categorical) on participants' abilities to name plants and classify plants as native or non-native (response variables). The response variables were entered into the model as number of correct answers minus the number of incorrect answers (using the 'cbind' function). Survey location was included as a random factor.

The global model contained all explanatory variables chosen *a priori*. Simplification of the global model was achieved based on Akaike Information Criterion (AIC) using the 'MuMIn' package (Barton 2011) which holds functions to compare all possible sub-sets of the global model. All models with ΔAIC <6 were retained (Richards 2008; Richards *et al.* 2011). Model averaging was used to calculate averaged parameter estimates and assess the relative importance of parameters using the natural averaging method (Burnham & Anderson 2002). R^2 values were calculated for the global models using the method described by Nakagawa and Schielzeth (2013). Parameters within the resulting averaged model were considered significant if the p-value was <0.05.

To test whether participants were better at identifying native or non-native plants a Mann Whitney U test was carried out as the data were not normally distributed. To explore if there was a correlation between participants' abilities to name plant species and their abilities to classify them as native or non-native, a Kendall's rank correlation test was carried out, as again the data were not normally distributed.

The relationships between responses to Likert-style questions exploring levels of support and motivation for learning plant identification skills (questions 3 to 6; ordinal data) and socio-demographic factors were analysed using a cumulative link model using the "ordinal" package (Christensen 2014). Model averaging followed this using the method outlined above. Models using all five response categories did not converge, therefore these were condensed to three categories – 'agree' (agree and strongly agree), 'neutral' and 'disagree' (disagree and strongly disagree).

4.3 Results

Participants scored a mean of 62.8% (s.e. = 0.19) when naming plant species. Participants were better at identifying plants if they were older, a member of an environmental, conservation or gardening organisation, if they were female, and if they lived in Cornwall (Table 4.2a and 4.3a; see Table A4.2 for results of global model). The model explained 14% of variation in the ability to identify plant species (marginal R^2 = 0.138; conditional R^2 = 0.141). Participants were significantly better at identifying native than non-native plants (Mann-Whitney U test, W = 2, p = 0.009). Japanese knotweed and Red valerian were correctly identified by less than 20% of participants (Figure 4.1a).

Participants scored a mean of 74.4% (s.e. = 0.11) when classifying plants as native or non-native, with Buddleia most commonly misclassified (Figure 4.1b). Participants better at classifying plants as native or non-native were male and had post-graduate qualifications (Table 4.2b and 4.3b; see Table A4.2 for results of global model). However, the model explained approximately 1% of variation in the ability to distinguish native/non-native plants (marginal and conditional R^2 = 0.010). There was no correlation between participants' abilities to name plant species and their ability to classify them as native or non-native (Kendall's rank correlation, z = 1.25, p = 0.21).

About half of participants (51.8%, n = 114) agreed or strongly agreed that knowing the names of plants was important to them. Higher levels of support were reported for children being taught plant names, for taking opportunities to learn plant names, and the majority (80%, n = 176) disagreed or strongly disagreed that they had no motivation to learn plant names (Figure 4.2). Socio-demographic factors were not significantly related to any responses, with the exception of gender for question 6 - 'I have no motivation to learn the names of plants' (p = 0.009, confidence intervals = 0.24, 1.67, estimate = 0.95, standard error = 0.36, z value = 2.61). 26.8% (n = 59) of participants reported being taught plant identification skills 'a lot', 34.5% (n = 76) 'some', 31.8% (n =

70) ‘a little’ and 6.8% (n = 15) ‘never’. Of the last group, five participants reported no methods of being taught and 10 reported being self-taught. 80% (n = 176) of participants reported learning plant identification skills from family, 47.7% (n = 105) being self-taught, 31.8% (n = 70) learnt at school, and 8.6% (n = 19) by attending courses.

4.4 Discussion

Using a novel methodological approach with real plants, rather than photographs or illustrations, this study asked three questions: (1) which socio-demographic factors influence people’s ability to name common plants and their ability to classify plants as native or non-native? (2) how is plant identification knowledge obtained?, and (3) what are levels of support and motivation for learning plant identification skills? The results of our study suggest that participants from a broad cross-section of society were better at correctly naming plants if they were female, a member of at least one environmental, conservation or gardening organisation, in an older age group, or a resident (rather than a visitor) in the study area. Conversely, success at identifying plants as native or non-native was higher if participants were male and had post-graduate qualifications. Overall participants correctly identified c.60% of common plant species, and were poor at recognising Japanese knotweed *Fallopia japonica*, which is a widespread high profile invasive non-native in the study region. Here we discuss our findings and their implications for engagement with conservation issues, the potential to gain human wellbeing benefits from biodiversity, and to engage in monitoring and tracking of biodiversity, including early warning of problematic species.

Participants in this study scored significantly lower when naming non-native compared with native plants – this is similar to a previous study that found children were worse at identifying non-native than native arthropods, birds and mammals (Huxham *et al.* 2006). Although not all non-native plants cause damage, those that do can have significant ecological and socio-economic costs (Simberloff *et al.* 2013). Of particular concern is that the widespread and problematic invasive non-native plant Japanese knotweed (Gozlan *et al.* 2013) was the second least identifiable plant. Japanese knotweed causes widespread ecological damage and can be expensive to control (Engler *et al.* 2011; Shaw 2014). In the UK Japanese knotweed is found within domestic gardens, where some of the problems it causes, particularly economic ones, can be most acute (RICS 2012). Given the private nature of domestic gardens, and the fact that many back gardens in particular, are secluded from view by passers-by, the presence of invasive non-native plants will be observed by only a few. It is therefore important that identification skills of such plants are high amongst the public to increase the chances of early identification and therefore successful and cost effective eradication.

The ability to identify invasive non-native plants in both domestic gardens and in the wider landscape is also important because it allows people to contribute towards citizen science projects that track them (Crall *et al.* 2012). Data generated this way are valuable for scientific research exploring the drivers of the distribution of invasive non-native plants (Wallace & Bargeron 2014), which subsequently can inform policy and management recommendations to reduce their ecological and socio-economic impacts (Mackechnie *et al*. 2014).

Participants were surprisingly good at identifying common native plants compared with most previous research using traditional methods of pictures and illustrations. For example, one study in Sheffield, UK found that visitors to an urban green space could identify only one out of four plant species common to that area from photographs (Dallimer *et al.* 2012). Another found that 86% of UK A-level students could only identify three or less out of ten wild flowers from illustrations (Bebbington 2005). This raises the possibility that the way in which identification skills are tested could be particularly important to the outcome. Using real plants is more reminiscent of the way people recognise and engage with plants in the environment as participants can smell and touch them, and gain a better idea of their size. Stagg and Donkin (2013) also used real plants to test identification skills, however they used potted weeds, fresh winter twigs and dried seed heads. The latter two are less representative of what one would see in the environment, and may explain why some participants in that study had poor plant identification skills.

Half of survey participants were members of at least one environmental, conservation or gardening organisation, which was a significant factor in predicting better identification skills. Although comparable data are scarce, this may be higher than in other settings (e.g. 26% of participants in a survey in Scotland were members of 'wildlife, conservation or heritage' organizations; Bremner & Park 2007). It is likely that people who are more interested in nature to begin with are more likely to join such organisations, and therefore reap the benefits such membership provides, such as increased access to nature reserves, volunteer opportunities and regularly receiving magazines filled with nature-related content. However, there is likely to be some level of positive feedback once joined, and that membership of such organisations encourages greater interest in and engagement with nature, thus leading to better plant identification skills. Membership of environmental and conservation organisations has been shown to be correlated with other types of nature-related knowledge (e.g. status of protected areas in the UK by their users; Booth *et al.* 2009), and environmental behaviour (e.g. willingness to pay to prevent oil pollution in coastal areas; Liu *et al.* 2009).

Our survey also asked about membership of gardening organisations, responses to which included national organisations such as the Royal Horticultural Society and local gardening organisations. The reasons for joining, and benefits gained from, gardening organisations will likely differ from those for conservation and environmental organisations. Nevertheless, membership of such organisations could likely be an important way for people to improve plant identification skills. Increasing membership of conservation and environmental, as well as gardening organisations, and working through and with them is potentially an important tool for engaging the public with nature (Booth *et al.* 2009), and thus improving plant identification skills.

Participants from Cornwall were significantly better at naming plants than participants from the rest of the UK. This could be explained by the much higher percentage of people in Cornwall who live in rural areas compared with the rest of the UK (61.4% and 18.5% respectively; ONS 2011). The increasing percentage of the world's population living in urbanized areas (predicted to be >80% by 2050: UN 2007) has frequently been linked to reduced access and opportunities to engage with nature (Pyle 2003; Miller 2005; Stokes 2006), which could lead to loss of plant identification skills. Promoting opportunities for urban residents to access green spaces could help mitigate this trend (Dallimer *et al*. 2012; Lin *et al.* 2014).

Age was the strongest predictor of plant identification knowledge, with those aged 60 and over being the best at naming plants. This correlation is consistent with previous research (e.g. Bebbington 2005; Woodland Trust 2013). Age has also been found to be an important factor in other ways that people engage with nature, for example, participation in bird feeding activities (Davies *et al.* 2012). It is, however, difficult to determine the causality of the relationship and whether younger generations will gain plant identification skills later in life or if this knowledge is being lost in younger generations. As evidence indicates that encounters with nature at an early age are important for promoting connections with nature (Stokes 2006), encouraging nature experiences for younger generations should be a priority if we are to increase motivation to learn and improve plant identification skills.

To improve plant identification knowledge, pathways by which people commonly obtain such knowledge could be invested in and promoted. In this study these were via family and by being self-taught, which might be considered 'less formal' methods of learning. The least frequently reported pathways of learning plant identification skills were through more formal methods - at school and through attending courses. It is important to consider how investment in these less frequently reported pathways could improve plant identification knowledge. Consideration could be given to how changes to the school curriculum and creative methods of teaching used can rectify this, as called for by others (Wandersee & Schussler 1999; Huxham *et al*. 2006; Stagg & Donkin 2013). Attending courses was the least frequent way participants reported learning plant identification skills: only 8.6% of participants reported learning this way. Whilst attending courses of this type is not suited to everyone's taste, consideration of potential barriers to attending such courses, such as time and money – although these might also be deeper rooted and due to cultural and social differences - could assist in unlocking the potential in learning via this method.

To implement practical actions to improve species identification skills people first need to be aware of the importance of identification skills and have motivation to improve them. However, the contrast between only half of participants agreeing or strongly agreeing that learning plant names is important, and the high support reported for taking opportunities to improve plant identification skills, further highlights that the relationship and gap between ecological attitudes and ecological behavior is complex and difficult to address (Kaiser & Fuhrer 2003; Clayton & Myers 2009). Therefore, any measures to improve plant identification skills need to address the reasons why people learn plant identification skills and why some do not think they are important; more qualitative research techniques, perhaps using in-depth interviews could assist with this.

There were several limitations to this study. The factors in the model explaining plant identification, and even more so, the model exploring knowledge of what was native or non-native explained little of the variation. However, the overall conclusions were not changed by the model selection process as the same factors were significant in the global models (see Table A4.2). This low explanatory power suggests that there are other unexplored variables contributing to these types of knowledge. It is also important to remember that this study was carried out in a 'post-industrial nation', where despite some plants still having cultural significance, plant identification skills have often become irrelevant for daily needs. For example, one study found that plant identification knowledge was much higher in India and Indonesia than in the UK, which they attribute to differences in culture and resource dependence in the three countries (Pilgrim *et al*. 2008). Therefore, perhaps the challenge lies in establishing the relevance and worth of plant identification skills (Pilgrim *et al*. 2008). One way in which this might already be happening for plants that have practical uses is through the renewed interest in foraging wild foods, particularly by younger generations (Lee & Garikipati 2011; Price & Randall 2014). Blackberries or bramble *Rubus fructicosus,* are the best example from our results to demonstrate this as they are one of the most commonly foraged foods in the UK (Price & Randall 2014).

The biggest challenge is perhaps how to increase motivation to learn identification skills for plants that do not have practical uses or cultural significance, such as some of the non-native species, particularly problematic invasive ones. To address this challenge there needs to be an increase in societal awareness and understanding of the relative costs and benefits of different non-native plants to biodiversity, as well as an increased awareness of the importance of early identification and eradication of problematic non-native plants. It is of profound importance that the challenges addressed in this study continue to be addressed to increase the likelihood that the benefits plant identification skills can bring are delivered, such as increased engagement with conservation issues, potential human wellbeing benefits, the monitoring of problematic species, and increased connectedness with nature (Miller 2005; Pyle 2003; Dallimer *et al.* 2012).

Table 4.1 Summary statistics for socio-demographic attributes of survey participants. The shorthand used in the model outputs is followed in brackets where applicable.

Variable	Summary statistics	
Age		
18 – 29	17.3%	(n = 38)
30 – 39	8.6%	(n = 19)
40 – 49	25%	(n = 55)
50 – 59	22.7%	(n = 50)
60 +	26.3%	(n = 58)
Gender		
Female	58.2%	(n = 128)
Male	41.8%	(n = 92)
Highest level of education (Education)		
1: ‘O’ level, GCSE, or equivalent or less	19.6%	(n = 43)
2: ‘A’ Level, AS Level, or equivalent	11.4%	(n = 25)
3: Further education or vocational training	15.45%	(n = 36)
4: First degree (e.g. BSc, BA)	30%	(n = 66)
5: Higher degree (e.g. MSc, MA, PhD)	22.7%	(n = 50)
If the participant was a member of a wildlife, conservation or gardening organisations (Member of)		
None	49.5%	(n = 109)
One	25.9%	(n = 57)
Two	10.9%	(n = 24)
Three or more	13.6%	(n = 30)
If the participant had a garden (Garden)		
Yes	90%	(n = 198)
No	10%	(n = 22)
Where the participant currently lives (Lives)		
Cornwall	48.1%	(n = 108)
Rest of UK	50.9%	(n = 112)

Table 4.2 Summary of results after model averaging for a) ability to name plants and b) ability to classify plants as native or non-native. See Table 4.1 for descriptions of explanatory variables. The base categories were: female; education level 1 ('O' level, GCSE, or equivalent or less); member of no wildlife, conservation or gardening organisations; if the participant did not a have a garden; and if the participant was currently a resident in Cornwall.

	Parameter Estimate	Standard Error	Adjusted Standard Error	z-value	P-value
a) Ability to correctly name plants					
Intercept	-0.276	0.180	0.181	1.529	0.126
Age (30-39)	0.572	0.174	0.175	3.263	0.001
Age (40-49)	0.870	0.135	0.136	6.394	< 0.001
Age (50-59)	1.179	0.142	0.142	8.288	< 0.001
Age (60+)	1.397	0.147	0.147	9.477	< 0.001
Gender (male)	-0.699	0.089	0.089	7.819	< 0.001
Member of (one)	0.308	0.112	0.113	2.739	0.006
Member of (two)	0.424	0.140	0.141	3.005	0.003
Member of (three)	0.682	0.149	0.150	4.547	< 0.001
Garden (yes)	0.259	0.149	0.150	1.724	0.085
Lives (rest of UK)	-0.232	0.095	0.096	2.424	0.015
b) Ability to classify plants as native or non-native					
Intercept	0.875	0.168	0.169	5.180	< 0.001
Age (30-39)	0.162	0.188	0.189	0.857	0.391
Age (40-49)	0.168	0.139	0.140	1.203	0.229
Age (50-59)	0.191	0.142	0.143	1.339	0.181
Age (60+)	0.015	0.135	0.136	0.111	0.912
Gender (male)	0.189	0.092	0.093	2.041	0.041
Education (2)	0.137	0.159	0.160	0.853	0.394
Education (3)	0.112	0.150	0.150	0.745	0.456
Education (4)	0.197	0.129	0.130	1.512	0.130
Education (5)	0.343	0.140	0.141	2.438	0.015
Member of (one)	-0.060	0.109	0.109	0.552	0.581
Member of (two)	0.104	0.148	0.149	0.697	0.486
Member of (three)	0.151	0.139	0.140	1.082	0.279
Garden (yes)	0.194	0.148	0.149	1.304	0.192
Lives (rest of UK)	-0.009	0.092	0.092	0.097	0.923

Table 4.3 Results of top 10 models based on AIC_c. df = degrees of freedom, weight = Akaike weight. See Table 4.1 for detailed descriptions of explanatory variables.

Intercept		**df**	**Log-likelihood**	**AICc**	**ΔAICc**	**weight**
a) Ability to correctly name plants						
-0.332	Age + Gender + Member of + Garden + Live	12	-479.07	983.6	0.00	0.514
-0.163	Age + Gender + Member of + Live	11	-480.65	984.6	0.93	0.323
-0.268	Age + Gender + Member of	10	-483.36	987.8	4.14	0.065
-0.412	Age + Gender + Member of + Garden	11	-482.32	987.9	4.27	0.061
-0.288	Age + Gender + Education + Member of + Garden + Live	16	-477.65	990.0	6.34	0.022
-0.097	Age + Gender + Education + Member of + Live	15	-479.41	991.2	7.53	0.012
-0.209	Age + Gender + Education + Member of	14	-482.32	994.7	11.06	0.002
-0.368	Age + Gender + Education + Member of + Garden	15	-481.21	994.8	11.14	0.002
-0.200	Age + Gender + Garden + Live	9	-492.45	1003.8	20.13	0.000
0.019	Age + Gender + Live	8	-494.89	1006.5	22.83	0.000
b) Ability to classify plants as native or non-native						
0.990	Gender	3	-407.631	821.4	0.000	0.188
0.819	Gender + Garden	4	-406.820	821.8	0.450	0.150
0.993	Gender + Live	4	-407.629	823.4	2.070	0.067
0.614	Gender + Garden + Education	8	-403.476	823.6	2.260	0.061
0.837	Gender + Education	7	-404.657	823.8	2.470	0.055
0.824	Gender + Garden + Live	5	-406.800	823.9	2.510	0.054
0.924	Garden	3	-409.154	824.4	3.050	0.041
0.968	Gender + Member of	6	-406.360	825.1	3.740	0.029
0.897	Education	6	-406.418	825.2	3.860	0.027
0.702	Garden + Education	7	-405.477	825.5	4.110	0.024

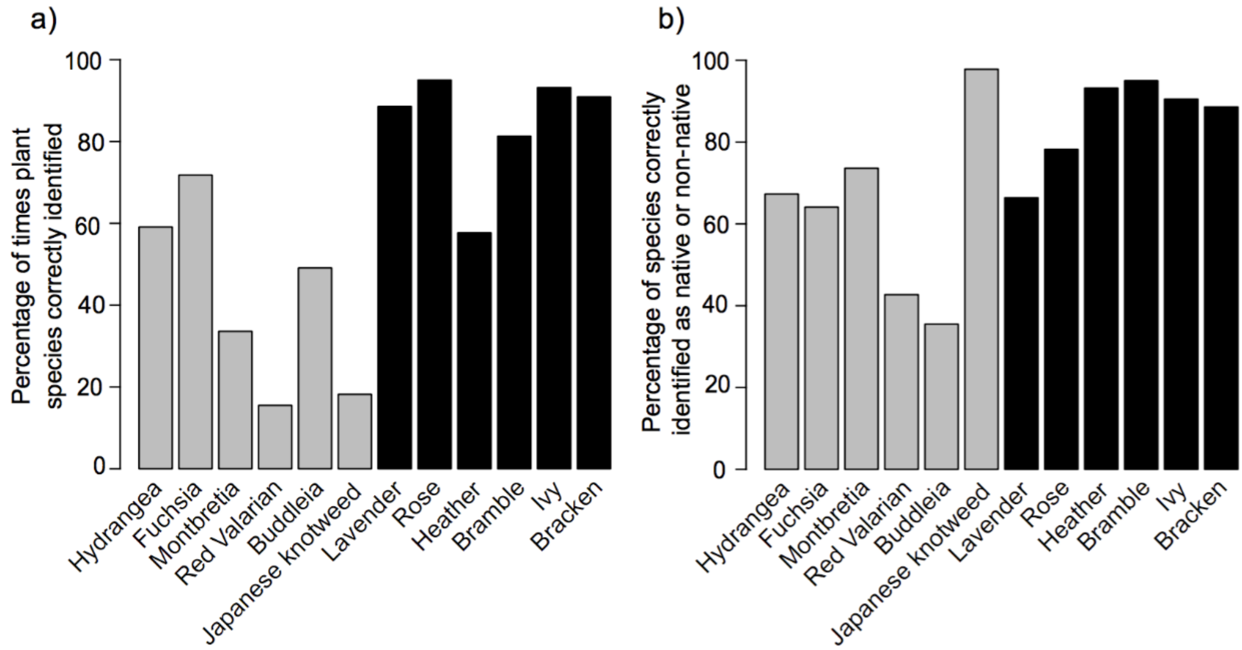

Figure 4.1 Results of plant identification survey for a) percentage of times each plant was correctly identified; b) percentage of times each plant was correctly classified as native or non-native. Light grey bars = non-native species; black bars = native species.

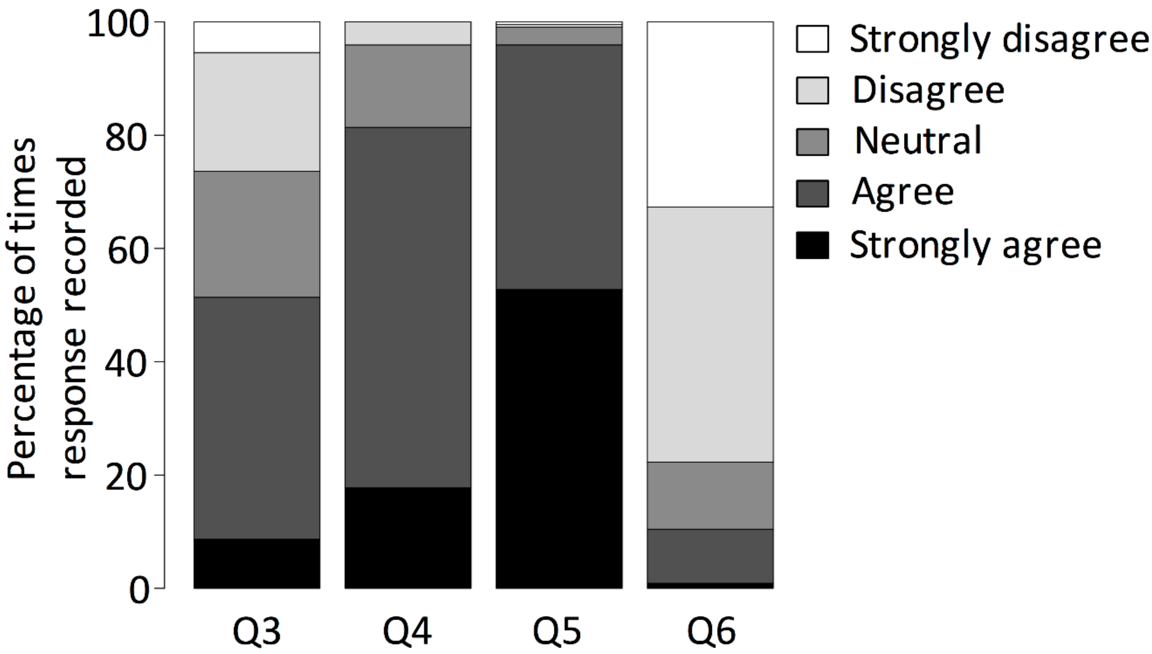

Figure 4.2 Responses to Likert-Style questions about attitudes towards plant identification and motivation to learn**.** Survey responses for Q3: Knowing the names of plants is important to me; Q4: I think children should be taught how to identify common plant species; Q5: If given the opportunity to improve my plant identification knowledge I would take it; and Q6: I have no motivation to learn the names of plants.

Chapter five

Once an INNP has been identified in a domestic garden, the individual(s) responsible for the garden needs to decide if and how to manage it. The individual(s) may already have some knowledge about the impacts of INNP and how to manage them, or they may have none. Either way, unless they are very knowledgeable on this topic, they will likely wish to obtain further information. In today's digital age, the internet is a common source of knowledge for a variety of topics. Content published on the internet is written by a diverse array of authors with different motivations for disseminating information. This diversity raises the question of how variable is internet-based information on a certain topic and might the collective discourse be confusing for the reader. Chapter five analyses internet-based information about Japanese knotweed, explores who is writing it and how. Greater understanding of internet-based information regarding INNP will help develop ways to increase accurate public understanding of the topic, and ways to mitigate potentially conflicting and confusing discourse.

Chapter 5:
Robinson B, Inger R, Crowley LS, Gaston KJ (2016) Weeds on the web: conflicting management advice about an invasive non-native plant. Journal of Applied Ecology. Early online.

Author contributions
I led the development of the idea for this chapter, collected the data, conducted the analyses, and wrote the manuscript.

Weeds on the web: conflicting management advice about an invasive non-native plant

Abstract

Invasive non-native plants (INNP) can have serious and widespread negative ecological and socio-economic impacts. It is therefore important they are managed appropriately. Within domestic gardens management decisions, which will tend to be made by individual members of the public, are likely to vary depending on (a) understanding of problems caused by INNP, and (b) knowledge of best practice.

Using content analysis, an approach seldom employed in an ecological context, this study analysed variation in internet-based information sources regarding INNP to determine how this collective discourse might influence risk perceptions and management decisions for domestic garden owners/managers. We used Japanese knotweed *Fallopia japonica* in the UK, as a case study, as it is one of the most ecologically and economically damaging INNP in the region. Analysis categorised the types of author disseminating information about Japanese knotweed, the relative frequency of documents between author categories, and variation in content and style between and within author categories.

We identified five author categories: environmental NGOs, control companies, government, media and the property market. There was extensive variation in document structure, topics discussed, references and links to other sources, and language style; sometimes this variation was between author categories, sometimes within author categories. The most significant variation in topics discussed between author categories was indirect socio-economic problems, with control companies discussing these most. The number of pieces of legislation referenced and the proportion of militaristic words used were also highly significantly different between author categories. Some documents used neutral terminology and were more circumspect, whilst others were more forceful in expressing opinions and sensational.

The author category returning the highest number of documents was the sub-category *local government*, the shortest of which contained neither links to other information nor

referenced any organisations. Further analysis of *local government* documents revealed conflicting advice regarding the disposal of Japanese knotweed waste material; confusion about this topic could result in decisions being made that spread Japanese knotweed further and are potentially unlawful.

The potential implications of our findings for the management of INNP in domestic gardens and societal perceptions of risks posed by INNP are discussed. To help prevent inappropriate management of INNP in domestic gardens, we recommend that local and national authorities collaborate and work towards disseminating more consistent messages about (a) the potential socio-economic and ecological problems caused by INNP, whilst avoiding hyperbole, and (b) the most appropriate management techniques.

5.1 Introduction

Invasive non-native plants (INNP) are a cause of significant global concern (CBD 2010; Simberloff *et al.* 2013). They can lead to biodiversity loss, alter ecological processes and impact ecosystem services (Vilà *et al.* 2011; Hulme *et al*. 2013). There are an increasing number of socio-economic impacts of INNP, for example, one study suggested losses from invasive weeds in the USA accumulate to at least US$35 billion annually (Pimentel *et al.* 2005).

Planting in domestic gardens is a major introduction pathway for non-native plants, some of which subsequently become invasive (Groves *et al.* 2005; Smith *et al.* 2006). Invasions are doubtless facilitated by the high areal coverage and proportion of green space contributed by domestic gardens in many western cities (Gaston *et al.* 2005; Loram *et al.* 2007; Gaston & Gaston 2011). Given that gardens can also play important roles in maintaining urban biodiversity and connecting otherwise fragmented urban habitats (Smith *et al.* 2006; Davies *et al.* 2008), it is important that INNP are managed in a way that minimises their negative ecological and socio-economic impacts. In domestic gardens people are largely free to manage the land 'as they please' (Gaston *et al.* 2005; Qvenild *et al.* 2014). There is considerable variation in public awareness and understanding of INNP (Gozlan *et al.* 2013), and in the extent and form of INNP management (van Heezik *et al.* 2013). Furthermore, a recent study found that <20% of a sample of the UK public could identify Japanese knotweed *Fallopia japonica* (chapter four), an INNP of particular concern in this region (Gozlan *et al*. 2013). However, research into the challenges associated with managing domestic gardens to restrict INNP impacts is limited compared with equivalent research for public spaces (Qvenild *et al.* 2014).

Knowledge and understanding of INNP and their management can be obtained by members of the public from multiple sources (Defra & GBNNSS 2009), such as government authorities, environmental professionals, media (formal and informal) and word of mouth. These sources are accessible - along with many others - via the internet. As the internet is one of the most regularly accessed sources of information in many westernised societies today for a range of topics (Flanagin & Metzger 2000; Miller &

Bartlett 2012), a significant amount of information on INNP in domestic gardens will be obtained in this way. This is reflected in a Google Trends analysis, which shows increasing frequency of Google searches for information on Japanese knotweed, a significant INNP, in the UK (Figure 5.1).

There is a vast amount of information on the internet, which is likely to be diverse given the broad range of sources, authors (Flanagin & Metzger 2000; Miller & Bartlett 2012) and agendas to disseminate information. It can be trustworthy, accurate and written by specialists (these do not necessarily always correlate); it is also prone to misinformation, selective truths and marketing propaganda (Miller & Bartlett 2012). This can make it hard to find complete and accurate information on a topic, as has been demonstrated, for example, for information relating to human health (Berland *et al.* 2001). Variation can sometimes be, in part, due to lack of scientific consensus.

Given that a diverse range of authors with different motivations disseminate information about INNP, this raises the questions: how variable (or consistent) is this information? And how might this influence risk perceptions and management decisions by those people responsible for INNP in domestic gardens? Secondary information sources can be particularly influential on risk perceptions when people lack direct experience of phenomena. Variation in how people interpret these secondary sources, combined with their knowledge/experience of similar risks, can create social amplification of risk. This can manifest itself in individual behavioural decisions, which can have social and economic consequences (Pidgeon *et al.* 2003). Variation in source content - for instance, in the topics discussed or signposting to further information - could lead to confusion about the ecology of INNP, the ecological and socio-economic problems they cause, and the most appropriate management techniques. If different internet sources provide conflicting views on management approaches, this makes it harder for homeowners to assess and decide on appropriate management decisions. If sources vary in their portrayals of the severity of the impacts of INNP, it could be unclear to the reader exactly why - or even *if* - they should be concerned. Furthermore, internet sources may vary in the language they use, a subject that has received increasing attention in INNP discourse (Gobster 2005). For instance, militaristic language within invasive species discourse, which is not uncommon outside of scientific literature, may have the positive rhetorical power of motivating action against INNP, might also create inflated or inaccurate perceptions of the problems, or limit the reader's confidence in a source's scientific credibility and objectivity (Gobster 2005; Larson 2005).

This study analyses how internet-based information sources regarding INNP available to those responsible for managing them in domestic gardens varies, then considers how this collective discourse might influence risk perceptions and management decisions. Understanding variation in internet discourse about INNP can help governmental authorities target and improve their communication, thereby potentially improving societal understanding of current best management practices for INNP in domestic gardens, and subsequently reducing their spread and impacts. Japanese knotweed in the UK is used as a case study as this is a region in which it causes widespread and serious ecological and socio-economic damage (Engler *et al.* 2011; Gozlan *et al*. 2013). The method we use however, can be applied to internet-based discourse of other INNP, and in different countries.

Japanese knotweed in the UK constitutes a valuable case study for several reasons. Originally introduced for ornamental purposes in the mid-1800s, Japanese knotweed has since become widespread and problematic (Beerling *et al.* 1994). It spreads highly efficiently by vegetative reproduction (Engler *et al.* 2011) and can regenerate from just a few grams of rhizome (Sasik & Pavol 2006). It causes ecological disturbance by outcompeting other plants (Engler *et al.* 2011), and through allelopathy, suppressing their growth (Dommanget *et al*. 2014). This has consequences for organisms at other trophic levels, by altering habitat structure or modifying availability of food sources (Engler *et al.* 2011). Japanese knotweed is estimated to cost the UK economy £165 million a year (Williams *et al.* 2010). It is named in several pieces of UK legislation, most notably the 'Wildlife and Countryside Act' (1981), under which it is an offence to plant or cause Japanese knotweed to spread in the wild, and the 'Environmental Protection Act' (1990), which requires correct waste material disposal methods (Bailey & Conolly 2000; Environment Agency 2006). Recently, Japanese knotweed has received extensive media coverage (Gozlan *et al*. 2013) relating to problems caused by its rapid spread.

5.2 Methods

5.2.1 Document selection

Documents for analysis were obtained using Google (www.google.co.uk) because it is the most popular search engine (Purcell *et al.* 2012). Two searches were conducted, first for "Japanese Knotweed" then for "*Fallopia japonica"*. The first 100 websites from each search (omitting sponsored links and duplicates) that provided management advice, general information or news articles were saved – these are referred to as 'documents' hereafter. Where websites contained multiple pages relating to Japanese knotweed, and these were immediately identifiable from the website's menu, all relevant pages were combined within one document for analysis. From the total 200 documents collected from both Google searches only UK-based sources (n = 113) were extracted for inclusion in the final analysis.

Author categories were developed and assigned to each document (Table 5.1). Documents that did not fit into these categories (n = 9) were omitted from further analysis. For example, Wikipedia has multiple authors and is frequently amended.

5.2.2 Document Analysis

Methods employed in this study build on content analysis, an approach frequently used in social science research to analyse the content of communications (in this case written text) to ascertain meaning and potential consequences (Bernard 2011; Krippendoff 2013). This method involves identifying 'themes' or 'codes' within text which are replicable and can therefore be analysed quantitatively (Bernard 2011).

First, the primary coder (BR) read the documents in their entirety to become familiar with the content, and then re-read and manually codified the documents systematically and iteratively into themes using Nvivo 10.0 (QSR 2012). Both inductive and deductive approaches were used to develop codes, drawing from existing literature on INNP discourse and environmental management. Codes were then refined through discussions between authors and a focus group of both social and natural scientists. To check for coding bias, 25% of randomly selected documents from each author category were also coded by a second coder (SC) for all elements of analysis. Agreement was assessed using Cohen's kappa, a measure of agreement between the two coders that accounts for agreement that would occur by chance (Bernard 2011). High agreement (>70%) indicated that the method is robust. Coding was subsequently modified through discussion between coders as required.

Data were primarily analysed quantitatively (methods outlined below). These results are illustrated with qualitative data to allow a more focused evaluation of emerging themes and patterns, particularly: the context of the text, relationships between codes, diversity in portrayal of the severity of the impacts of INNP, exploration of the ways this collective information is potentially conflicting and/or confusing, and possible implications for management decisions. Quotes are ascribed to author categories only, as the intention is not to discredit advice given by a particular source.

(i) Analysis of all documents

The first part of the analysis considered all qualifying documents from the Google searches (n = 104) and was structured so that it might be applicable to any problematic INNP in domestic gardens.

The following codes were developed:

1. *Number of words*

The total number of words per document was calculated as a coarse measure of the amount of information a document contained. Although not a direct measure, this helps to identify outliers (e.g. very short documents) and was necessary for further analysis (proportion of words of language type). Word count included titles, sub-titles and picture captions, but excluded unrelated links and adverts.

2. *Topics discussed*

The topics discussed within different documents potentially affect the reader's knowledge and understanding about what the problems of INNP are, whether and why they should be concerned, and the most appropriate management methods. Coded topics were totaled up for each document, but repetition of codes within a document was discounted. See Appendix 5.1 for full details of codes.

a) *Problematic traits*

These were the biological traits of Japanese knotweed that make it problematic in its introduced range. The codes were*: Japanese knotweed…* grows fast; grows tall; can regenerate from small fragments; can survive extreme conditions / grow in a wide variety of habitats; has rhizomes that can survive extreme conditions; has rhizomes that can survive extended dormancy periods; and has roots that extend a long way vertically and/or horizontally

b) *Problems caused:* A 'problem' was defined as any (real or potential) negative consequence of Japanese knotweed presence. The primary coder identified an exhaustive list of problems identified within the documents. These were then categorised into three broad categories of problem, developed iteratively during focus group discussion (see above).

The three broad types of problem were:

i) *Direct socio-economic problems* directly affecting the human environment by physically altering either natural or human-made structures. The codes were: *Japanese knotweed can*… damage gardens; increase flood risk; damage hard human-made structures; reduce visibility; trap litter and vermin; have a negative aesthetic impact; cause a trip hazard; impact recreational activities; cause a fire hazard; and, its presence on riverbanks can lead to soil erosion.

ii) *Indirect socio-economic problems* arise because direct socio-economic effects of Japanese knotweed have knock-on second order impacts on the social environment or have potential associated economic costs. The codes were: *Japanese knotweed…* is costly to eradicate or control; reduces land / property value; can cause mortgage problems; can cause legal disputes; can cause delays to planning applications and building development projects; and, can cause insurance problems.

iii) *Negative ecological impacts:* These are effects that have a negative impact on other flora and fauna, biodiversity or ecological processes. The codes were: *Japanese knotweed can…* cause a change in biodiversity; impact trophic reactions; have a negative effect on animals; and, have a negative effect on plants.

3. References and links to other sources

During analysis it became clear that there was large variation in specific organisations signposted, links provided to further information and INNP legislation referenced. It is valuable to consider these components of a document for two reasons. First, they provide the reader with additional sources of information, allowing them to crosscheck facts and develop their understanding of the topic (Sillence *et al.* 2006). Second, they may be rhetorical tools used by different sources to convince the reader of the validity of the information contained within the document.

a) Specific organisations signposted and links provided: These were totaled up for each document. Examples include: Environment Agency; Defra (Department of Environment, Food and Rural Affairs); control companies; and scientific references.

b) Legislation referenced: The total number of pieces of legislation quoted or referred to (specifically relating to Japanese knotweed) were totaled up for each document.

4. Language Style

Two types of language style were analysed, informed by literature on INNP and environmental discourses: science/technology and militaristic. For analysis of language style words were initially drawn from examples used in similar analyses (Webb & Raffaelli 2008 for science/technology; Larson 2005 for militaristic words). Additional words identified within these styles by the coders were added to the analysis. Words were coded as many times as they arose, but omitted if they had negative qualifiers or were part of a name. The proportion of words within a document using these terminologies was calculated.

a) Science/technology terminology: Words relating to science and technology may contribute towards an increase in perceived legitimacy of the source (Webb & Raffaelli 2008). Words coded were: *ecologist; ecology; biologist; biology; scientific; data; professor; research; monitoring; evaluation; evidence; measure; record* and *rhizome*. Scientific names of flora and fauna were also coded for.

b) Militaristic terminology: Militaristic words are common in invasive species discourse and may influence the readers' perception of invasive species (Larson 2005). Words coded were: *war; enemy; weapon; attack; offensive; battle; solider; fortress; conquer* and *guerrilla*.

5.2.3 Statistical Analysis

Differences in codes (the response variable) between the five main author categories (explanatory variable) were analysed using R 3.0.2 (R 2009). Sub-author categories were combined to increase sample size and statistical power of analyses (e.g. *mainstream media* and *other media* combined, see Table 5.1). For the response variables of word count (log transformed) and proportion of words per document with a scientific or militaristic association (arc-sine square root transformed) (elements: 1a; 4a; and 4b of part (i) of analysis respectively), linear models were developed. Linear models were interpreted by comparing the full model with the null model using the F-statistic and P-value.

The following response variables were explored using generalized linear models (Poisson distribution) and interpreted by comparing the full model with the null model using the Chi squared statistic and P value: number of occurrences of (i) problematic traits, (ii) direct socio-economic problems, (iii) indirect socio-economic problems, (iv) ecological impacts, (v) specific organisations signposted and links provided, and (vi) legislation referenced (elements: 2a; 2b.i; 2b.ii; 2b.iii; 3a; and 3b of part (i) of analysis respectively). Author category was included as a fixed factor and document ID as a random (intercept) factor to account for over dispersion. In all models *environmental NGO* was the base (reference) category.

To explore differences in codes within author categories the error around the mean was assessed. The *local government* category was chosen as a focus for analysis for within-author variation as it contained the greatest number of documents, and it is reasonable to assume that local government publications are a regularly consulted and trusted source of information for environmental issues as they provide information, advice and authority for a broad range of environmental and societal issues. For the same reasons, *local government* documents were also chosen as a focus for part two of the analysis.

(ii) Analysis of local government documents' disposal advice

It is important to provide clear advice about waste disposal of Japanese knotweed, as it can regrow from small fragments of rhizome (Sasik & Pavol 2006), and incorrect disposal of waste material can result in further spread of this plant. Therefore, the second section of analysis examined discussion of waste disposal within *local government* documents, and whether the information therein was conflicting and/or confusing.

Word searches were used to identify sections of *local government* documents that contained advice on waste material disposal. Words searched were: *disposal, rubbish, landfill* and *waste*. Relevant sections were then re-analysed and codes relating to specific disposal advice were developed iteratively. Authors then evaluated whether and how any disposal advice was conflicting.

5.3 Results

Of the 104 documents included in the final analysis five author categories were identified, with two broken down into sub-categories (Table 5.1; see Table A5.1 for author categories descriptions and list of documents). The *local government* and *control company* categories contained the most documents. Sources of documents were diverse, for example *mainstream media* contained articles from a range of sources (1 Financial Times; 4 BBC; 1 Daily Mail; 3 Guardian; 2 Daily Telegraph) and *local government* documents represented a large geographic range, including both urban and rural areas.

(i) Analysis of all documents

Number of words per document was not statistically different between author categories ($F_{4,99} = 1.82$, $P = 0.132$; Figure 5.2a). The average length of a document was 1575.6 (s.e = 276.3) words: the shortest was 188 words, the longest 22,305. Within documents from local government sources there was considerable variation in word count, with the shortest only 266 words, the longest 9,764. The shortest *local government* document contained neither links to other information nor referenced any organisations.

The numbers of problematic ecological traits mentioned per document was approaching a significant difference between author categories and had large standard errors around the mean (χ^2_4 = 9.05, P = 0.060; Figure 5.2b). All *local government* documents mentioned at least one problematic trait, with a maximum of six (Figure 5.3a). The problematic ecological trait mentioned most frequently, in 70.2% (n = 73) of documents, was that Japanese knotweed could regrow from a small fragment of rhizome.

The number of direct socio-economic problems discussed per document was marginally significantly different between author categories (χ^2_4 = 9.58, P = 0.048; Figure 5.2c). In 30% (n = 9) of *local government* documents no direct socio-economic problems were mentioned (Figure 5.3b). The most frequently mentioned direct socio-economic problem, in 78.8% (n = 82) of documents, was that Japanese knotweed could cause damage to hard surfaces. However, portrayal of the severity of this issue was diverse. At one end of the spectrum, some authors implied that this is extremely problematic, for example, claiming that Japanese knotweed can "burrow into [building] foundations" (*media* document). Other authors were more circumspect, explaining that damage caused depends on the type of structure; damage to temporary structures such as greenhouses, for example, was reported as much more likely than damage to the foundations of houses. One *property market* document discussed this issue in depth and suggested that perceptions are often based on "misunderstandings and overreactions".

The number of indirect socio-economic problems discussed per document was highly significantly different between author categories (χ^2_4 = 27.75, P<0.001; Figure 5.2d). *Control companies* mentioned these problems most frequently, and *environmental NGOs* least. No indirect problems were mentioned by 30% (n = 9) of local government documents (Figure 5.3c). The indirect socio-economic problem mentioned most frequently, in 51.9% (n = 54) of documents, was that Japanese knotweed is costly to control. Some documents were vague about cost - one *local government* document simply noted, "it can be expensive", whereas others attempted to quantify control/eradication costs. Estimates ranged from £1 per m^2 (*local government* document), to "well over £1,000" per m^2 (*national government* document); however, the latter represents costs to development sites and the former to domestic property. Other sources, including multiple *control company* documents, stated that the presence of Japanese knotweed can add 10% to the budget of a development. The cost of eradicating Japanese knotweed was quoted as '£1.56 billion' by 12.5% (n = 13) of documents, across all except *national government,* author categories, referring to the calculations of a Defra (2003) report.

The number of ecological problems discussed per document was not significantly different between author categories and had large standard errors around the mean (χ^2_4 = 6.63, P = 0.157; Figure 5.2e). No ecological problems at all were mentioned in 16.7% (n = 5) of *local government* documents (Figure 5.3d). The most common ecological problem, mentioned in 56.7% (n = 59) of documents, was that Japanese knotweed outcompetes other plants. Some documents communicated this in neutral language; for example, one *local government* document noted that Japanese knotweed "often outcompetes existing plant communities". Others expressed this more sensationally, e.g. "it smothers rival plants" (*mainstream media* document).

The number of organisations referenced per document did not differ significantly between author categories (χ^2_4 = 4.59, P = 0.332; Figure 5.2f). The most commonly referenced organisation, mentioned by 75.9% (n = 79) of documents, was the Environment Agency, a UK government organisation responsible for national environmental protection issues. In 26.9% (n = 28) of all documents reference was made or a link was provided to the guidelines produced by the Environment Agency in 2006 (updated 2013). These guidelines provide advice aimed at the development and haulage industry, but are freely available and also relevant to homeowners. A link to the Environment Agency guidelines was provided by 20% (n = 6) of *local government* documents. No links to organisations were mentioned or provided by 6.7% (n = 2) of *local government* documents and 36.7% (n = 11) referenced only one (Figure 5.3e).

The number of pieces of legislation referred to per document was highly significantly different between author categories (χ^2_4 = 39.49, P<0.001; Figure 5.2g). *Control company* and *government* documents referenced most legislation, and *media* and *environmental NGOs* the least. Within *local government* documents, 10% (n = 3) mentioned no legislation (Figure 5.3f). Some documents simply mentioned the name of legislation and a brief description, for example: "Wildlife and Countryside Act (1981) –

It is an offence to plant, or cause knotweed to grow in the wild" (*local government* document). Others provided more detail about the implications of legislation in relation to management decisions and the potential consequences of ignoring this. For example, one *local government* document explained that offences under this legislation include 'fly-tipping' (illegally dumping) material containing Japanese knotweed.

The proportion of science/technology words per document was not statistically significantly different between author categories ($F_{4,99}$ = 0.60, P = 0.661, Figure 5.2h). However, the two documents with the highest proportion of scientific words contained very few words overall, at 266 and 283 words (*local government* document and *environmental NGO* document, respectively). Further examination of these documents revealed that despite the high proportion of scientific language, very little in the way of scientific information was communicated.

The proportion of militaristic words per document, however, was significantly different between author categories ($F_{4,99}$ = 5.23, P = 0.001; Figure 5.2i), with *media* documents containing the most. Examples of more extreme use include "reclaiming the war torn landscape" or "more like a guerrilla force than a thug" (both *other media* documents). Only 10% (n = 3) of *local government* documents used militaristic terminology.

(ii) Analysis of local government documents' disposal advice

All *local government* documents provided some advice on disposal of Japanese knotweed (n = 30). Some of this advice, however, related only to prohibited actions, e.g. "Cut material must not be removed from site and cannot be composted", thereby providing little direction as to best management practice. Other documents gave very detailed advice, subdivided into recommended practices for onsite and offsite disposal. Contact details for companies that dispose of Japanese knotweed were provided by 13.3% (n = 4) of *local government* documents. One additional document provided locations of regional waste disposal facilities.

Advice about composting was identified as a point of possible confusion. Advice as to whether or not Japanese knotweed should be composted at home was provided by 33.3% (n=10) of *local government* documents. Three documents stated it must *not* be composted at home and one that it *can* be composted at home, providing, however, no further detail about how and when. The remaining six documents explained that Japanese knotweed can be composted at home, but specified that caution should be exercised (e.g. by only composting dried stems).

Analysis revealed repetition of sentences, or even paragraphs, between *local government* documents. Some referred the reader to other *local government* documents. For instance, 16.7% (n=5) of *local government* documents directed readers to advice given by Cornwall Council.

5.4 Discussion

Management of INNP in domestic gardens is likely to vary depending on understanding of the problems they cause and knowledge of best practice. This study sampled internet sources of information regarding Japanese knotweed, a particularly problematic INNP occurring within domestic gardens in the UK. Analysis considered the types of authors disseminating such information, their relative frequency, variability of content and style between and within sources and whether the collective discourse is potentially conflicting and confusing. Here we consider the impact the findings might have on risk perceptions and management decisions about INNP in domestic gardens.

The author category containing the highest number of documents was *local government,* followed by *control companies*, then *media,* suggesting that these sources are likely to be accessed more frequently than other author categories. Whilst *local government* and *control company* documents are perhaps more likely to be consulted by people seeking information about Japanese knotweed, previous research suggests public understanding of invasive non-native species more generally, and on a day-to-day basis, is largely based on media reports (McNeely 2001).

The most significant variation in topics discussed between author categories was indirect socio-economic problems (e.g. devaluing property). Many of these are emerging issues at present specific to Japanese knotweed in the UK. It is important to raise awareness about the potential socio-economic problems associated with Japanese knotweed, as this facilitates development and implementation of mitigation strategies. However, incomplete or inaccurate communication about them could inflate or attenuate risk perception. Unfortunately, maintaining clear and accurate messages can be challenging, as scientific research on socio-economic problems associated with Japanese knotweed is lacking. Conversely, perhaps a greater scientific understanding of the ecological problems contributed to the lack of a variation in discussion of this topic between documents

For some authors, focusing on potential socio-economic problems associated with Japanese knotweed could be an advantageous rhetorical tool. For example, c*ontrol companies* referred most frequently to potential indirect and direct socio-economic problems. They also identified a high number of ecological traits, referenced more legislation than other author categories, and multiple *control companies* highlighted the potential extremities of Japanese knotweed removal costs. The high number of *control company* documents in the results is likely due to their use of search engine optimization to persuade readers to employ their services. This potentially produces both positive and negative outcomes. If property owners are convinced of the potential severity of the risks associated with Japanese knotweed, they may be more likely to employ professional control companies, thereby limiting the potential for mismanagement, further spread and damage. However, small-scale occurrences of Japanese knotweed in domestic gardens may not require professional attention to be effectively controlled. Consequently, overemphasis of risks may result in unnecessary anxiety and expenditure by householders, and inflate societal perception of the risks posed by INNP.

Some *local government* documents provided in-depth discussion about the problems caused by Japanese knotweed and detailed advice about how to manage it in domestic gardens. Overall, however, the information provided was highly variable in word count, topics discussed, links to further references and legislation discussed. Furthermore, conflicting management advice was identified within *local government* documents regarding how to dispose of Japanese knotweed waste material. This raises the concern that if those responsible for domestic gardens consult only the website of their local government authority, the quality and clarity of the information received could vary geographically.

The Environment Agency (EA) guidelines was the longest document in the analysis, and also the source most frequently referenced by others. This is likely to be a reliable source for several reasons. First, the EA works closely with other government agencies and departments, local councils and communities (EA 2014) and indeed, the report was written with input from Defra and National Rail. This collaborative approach to dissemination arguably strengthens the validity and legitimacy of information given. Second, the document has undergone several revisions to keep it up to date. Finally, government organisations have a formal responsibility to provide accurate information. The frequent citation of this document is likely due to the extensive information it contains, and because people in the UK generally trust government to provide accurate information (Briggs *et al.* 2002). Although this document may be too detailed for many responsible for managing domestic gardens, useful information can be extracted, and it should be signposted or summarised where possible.

As previously mentioned, the document style adopted depends on the author's motivation, and is in part, likely due to lack of scientific consensus on the severity of impacts. Some documents discussed the potential problems of Japanese knotweed in neutral terms, whilst others expressed opinions more forcefully, and demonstrated evidence of hyperbole. *Media* documents used the most militaristic language and stronger rhetoric. Presumably these are journalistic tools to create more stimulating stories, however concerns have been expressed that inappropriate language could have multiple consequences, including loss of scientific credibility and inaccurate societal perception of risk of INNP (Larson 2005). Media content analyses covering a range of human-wildlife conflicts have highlighted how framing of these issues can influence risk perceptions and behaviours (Jacobson *et al*. 2012; Sakurai *et al*. 2013). Increased communication between scientists and the media has been suggested as a way to mitigate these impacts (Barua 2010).

Information from such a wide range of sources will undoubtedly be diverse given the broad range of authors, motivations for writing, and economic and political interests. This diversity, combined with variation in visual design, trust and credibility individuals assign to websites (Sillence *et al.* 2006), the number of articles read on the subject (many internet users only read one or two; Miller & Bartlett 2012), and that many people will obtain information about INNP from non-internet sources, all heighten the potential for variation in societal understanding of the problems posed and risk, potentially leading to social amplification of the risks (Pidgeon *et al.* 2003).

Given that information on INNP in domestic gardens provided by many sources cannot be regulated, it is important that government authorities provide clear, detailed and consistent information on this topic. This could be accomplished by providing balanced and neutral discussion of a range of potential ecological and socio-economic problems caused by INNP, communicating clear and consistent messages about appropriate management methods, directing readers towards key management guidelines, highlighting a range of relevant legislation, and providing detailed information on waste disposal methods and local waste disposal facilities. Greater collaboration between local and national governmental departments, and development of a generic template that local government authorities could adapt for their own use, could help to deliver more consistent messages. Some evidence of coordination was observed, such as inputs from multiple stakeholders for some documents, cross-referencing between local and national government documents, and referencing advice from authorities who have invested more in researching, recording and promoting public understanding of INNP (e.g. Cornwall Council). Furthermore, it is likely that a lack of scientific consensus and knowledge gaps are contributing towards variation in internet-based discourse regarding Japanese knotweed. It is important that the scientific studies regarding INNP that have been done are reviewed regularly and made widely accessible. A good example of this is the series about INNP by the Canadian Journal of Plant Science, which reviews unpublished and published literature.

Despite content analyses being common and well-developed within social scientific research, such analyses in environmental management discourse are relatively scarce (Webb & Raffaelli 2008). This method could be used to analyse internet-based discourse of other INNP, and in different countries. The results could guide recommendations to improve societal knowledge, understanding and best-practice management, thereby decreasing the impacts and spread of INNP.

Table 5.1 Number of documents within author categories and sub-categories.

Author category	Number of documents
1. Environmental NGO	8
2. Control Company	29
3. Government organisations	
a) National	8
b) Local	30
4. Media	
a) Mainstream - online newspapers	11
b) Other (blogs etc.)	11
5. Property market	8

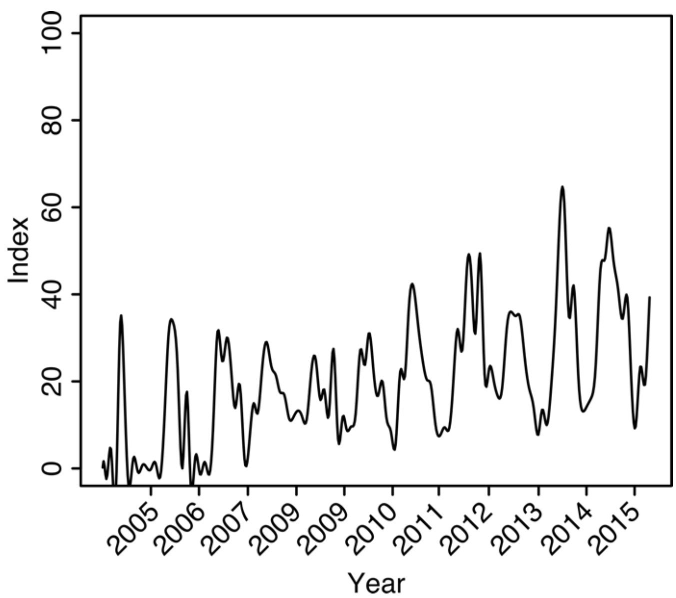

Figure 5.1 Index of number of times 'Japanese knotweed' was searched in the UK using Google.

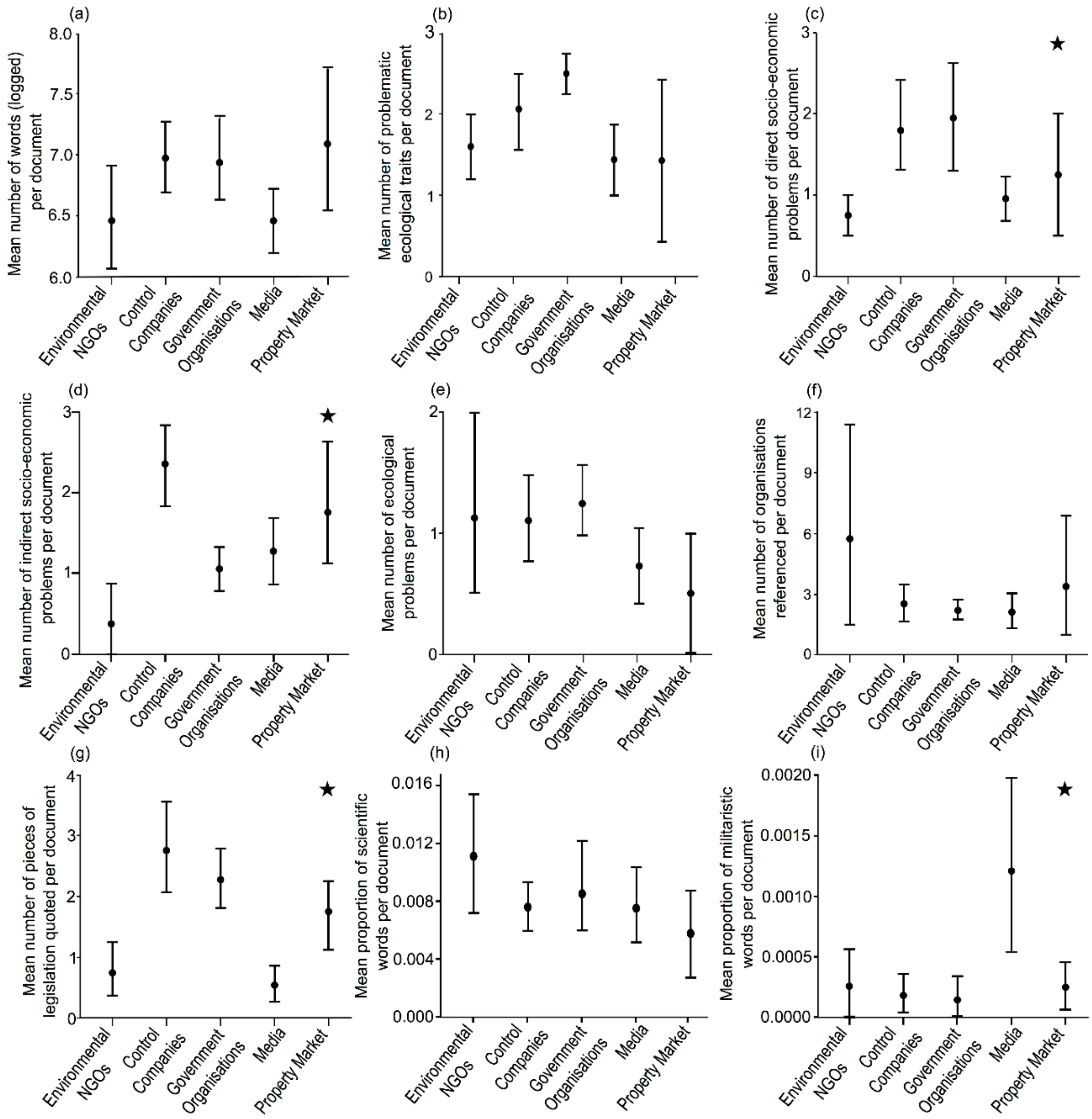

Figure 5.2 Variation between author categories in mean number of a) words (log-transformed); b) problematic ecological traits mentioned; c) direct socio-economic problems discussed; d) indirect a socio-economic problems discussed; e) number of ecological problems discussed; f) specific organisations referenced and links provided; g) pieces of legislation referenced; h) proportion of scientific words; i) proportion of militaristic words. Stars mark significant differences between author categories.

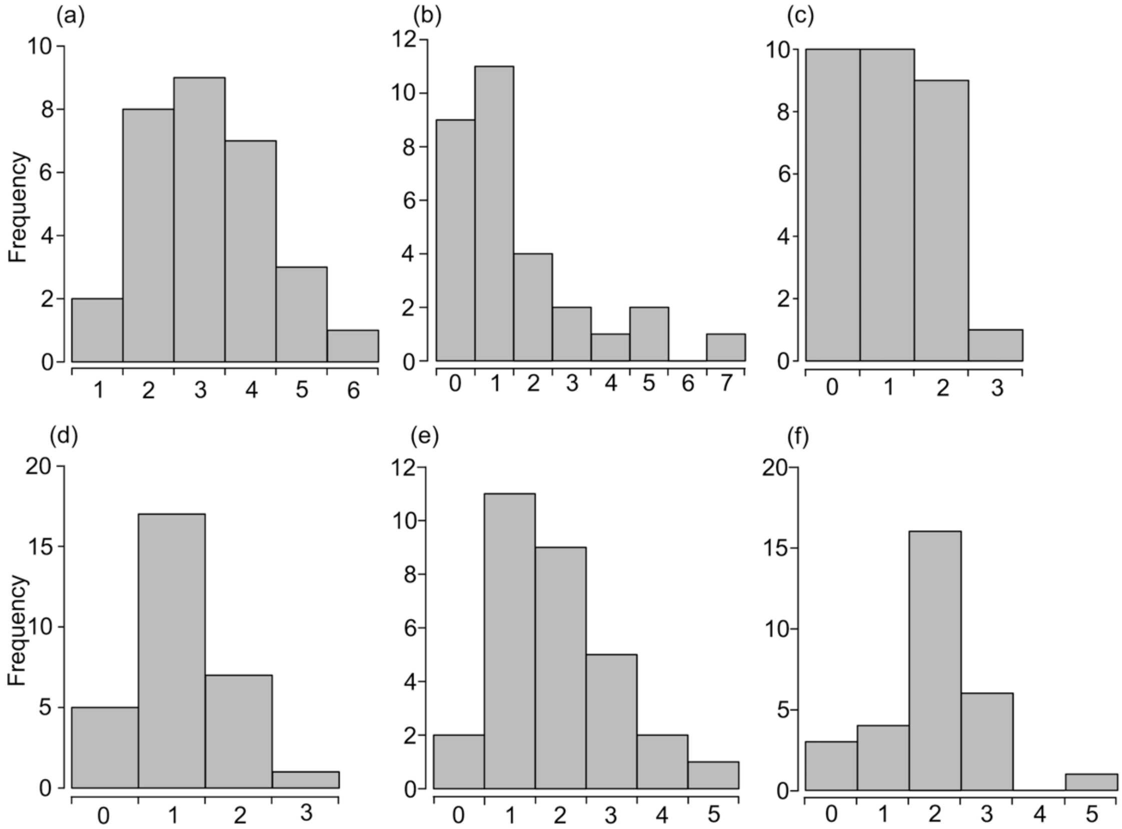

Figure 5.3 Frequency distributions of coded content or ‘themes’ within *local government* documents of number of a) problematic ecological traits discussed; b) direct socio-economic problems discussed; c) indirect socio-economic problems discussed; d) ecological problems discussed; e) specific organisations referenced and links provided; and f) pieces of legislation referenced.

Chapter six

Chapter five explored what information is available to those responsible for managing INNP in domestic gardens and considered how this might influence their management decisions within their gardens. It found large variety in the types of authors disseminating information about the impacts and management of Japanese knotweed. Some of this information is potentially misleading, over-emphasises the risks and perhaps collectively is confusing. Chapter five discussed the different portrayals of risk within internet discourse and considered if any might be resulting in amplification (or attenuation) of risk. It raises the point that how an individual decides to manage Japanese knotweed within a garden they are responsible for depends on their perception of the risks it poses therein. Despite a growing body of literature on perceptions of environmental risks generally, including some on INNP, no research has specifically addressed perceptions of risk of the impacts that INNP can have within gardens. Chapter six explores perceptions of risk of INNP within domestic gardens and considers the predictors of these risk perceptions. Identifying predictors of perception of risk can assist in informing the design of risk communication, education and awareness strategies to reduce the ecological and socio-economic impacts of INNP.

Chapter 6:
Robinson BS, Inger R, Gaston KJ. Drivers of risk perceptions about invasive non-native plants in domestic gardens.
This chapter is under review with Biological Invasions.

Author contributions
I developed the idea for this chapter, designed the survey, collected the majority of survey responses, conducted the analyses and wrote the manuscript.

Drivers of risk perceptions about invasive non-native plants in domestic gardens

Abstract

How people perceive risks posed by invasive non-native plants (INNP) can influence attitudes and consequently behavioural decisions. Although some drivers of risk perception have been identified, research has not determined those for INNP in domestic gardens. This is concerning as domestic gardens are where people most commonly encounter INNP, and where impacts can be particularly acute.

Using a survey approach, this study determined the drivers of perceptions of risk of INNP in domestic gardens and which risks most concern people. Japanese knotweed *Fallopia japonica,* in the UK, where it is problematic INNP in domestic gardens, was used as a case study. Possible predictors of risk were chosen a priori based on variables previously found to be important for environmental risks.

We found differences in perceived risk of Japanese knotweed depending on people's occupation, their direct experience of the species in a domestic context, their geographical proximity to the risk, their age and level of education. Concern about the damage Japanese knotweed could do to the structure of a property was reported as the second highest motivation to control it by the majority of participants, however, the perception of threat from this risk was rated as relatively low.

To reduce the impact and spread of INNP we highlight the need for clear and accurate risk communication within discourse about this issue. The drivers identified in this study could be used to target awareness campaigns to limit the development of over- or under-inflated risk perceptions.

6.1 Introduction

Invasive non-native plants (INNP) are a significant driver, as well as a product of, global environmental change (Simberloff *et al*. 2013; Blackburn *et al.* 2014). INNP often pose major risks to the environment, ecosystem services and human well-being (Pejchar & Mooney 2009; Vilà *et al.* 2011; Jeschke *et al*. 2014). These risks are likely to be greatly exacerbated as anthropogenic pressures on the natural environment increase (Banks *et al*. 2014).

The risks posed by INNP are managed and mitigated by people. However, the details and extent of the perception of such risks are inherently highly variable between individuals (Slimak & Dietz 2006; Vanderhoeven *et al.* 2011; Gozlan *et al.* 2013), are largely species dependent (Sharp *et al.* 2011; Gozlan *et al.* 2013; Verbrugge *et al*. 2013), and do not always correlate with actual ecological risk (Andreu *et al.* 2009; Gozlan *et al*. 2013). People are generally poor at assessing risks (Wachinger *et al.* 2013), frequently exaggerating some whilst downplaying others (Clayton & Myers 2009). The processes that lead to development of perceptions of risk are complex (Slovic 1999). Whilst there is debate over the levels of rationality and subjectivity involved (Slovic 1999; Sjoberg 1999), certain factors have recurrently been found to influence their development (Slimak & Dietz 2006). These include, for example, direct or indirect experience of a risk, proximity to the risk, and certain socio-demographic variables (e.g. age, education and gender; Kasperson *et al.* 1988; Flynn *et al*. 1994; Gustafson 1998; Slovic 1999; Carlton & Jacobson 2013; Wachinger *et al*. 2013).

How an individual perceives the risks of a specific INNP is central to determining their attitudes towards it, and subsequently their behaviour (Fischer & van der Wal 2007; Estévez *et al.* 2014). For example, divergent perceptions about the risks from INNP might result in conflict over management approaches, priorities, or even in opinions regarding whether they should be controlled at all (McDaniels 1997; Estévez *et al*. 2014). In domestic gardens, where the management of INNP is largely the responsibility of the owner or tenant of a given garden (Qvenild *et al.* 2014), the consequences of variation in perceptions of risks of INNP are likely to result in spatial heterogeneity in how INNP are managed therein.

INNP in domestic gardens can pose serious ecological risks, both within the garden and, if they escape, in the wider environment (Groves *et al.* 2005). Furthermore, the risks posed by INNP in domestic gardens can result in large economic costs (McDermott *et al.* 2013), and can cause high levels of anxiety. Mismanagement of INNP in domestic gardens could increase the ecological and socio-economic impacts INNP have, encourage their spread (van Heezik *et al.* 2013), and be detrimental to the wellbeing, biodiversity and ecosystem services that gardens can provide. The wellbeing benefits gardens can deliver, such as providing a space for leisure and social activities (Bhatti & Church 2004), opportunities to connect with nature (Restall & Conrad 2015) and opportunities to gain ecological knowledge and skills (Barthel *et al.* 2010), will only become more important in an increasingly urbanised world (UN 2010). Similarly, the significant contribution domestic gardens make to urban ecosystem functioning and habitat connectivity in many westernised countries, due to the large proportion of urban land they cover, will also become increasingly important as urbanisation increases. For example, private gardens account for over 20% of land cover in some UK cities (Loram *et al.* 2007) and over 35% in New Zealand (Mathieu *et al*. 2007).

Research into INNP in domestic gardens is relatively scarce (Qvenild *et al.* 2014). This is especially true of studies considering the perceptions of INNP. Studies that have examined perceptions of INNP in domestic gardens have largely focused on their categorisation as native or non-native, and their perceived level of invasiveness (e.g. Zagorski *et al.* 2004; Qvenild *et al.* 2014), rather than the perception of risks that specific INNP pose.

In this paper, we employ a survey approach to determine the factors influencing people's perception of the risks from INNP in domestic gardens, and which risks concern them most. The variables selected for the survey as potentially influencing perception of risk of INNP were chosen *a priori* based on knowledge of how they influence perceptions of other environmental risks. The results of this analysis help to reveal whether and why people might develop over- or under- inflated perceptions of risk. Furthermore, identifying predictors of perception of risk can assist in informing the design and targeting of risk communication, education and awareness strategies to reduce the ecological and socio-economic impacts of INNP. We use Japanese knotweed in the UK as a case study, as it exemplifies many of the risks surrounding INNP in domestic gardens, as well as having a number of additional risks when present on domestic property (e.g. it might devalue property; van Ham *et al.* 2013). Data were collected in Cornwall, a county in the southwest of the UK.

6.2 Method

6.2.1 Japanese knotweed

Introduced as a desirable garden plant in c.1850 (Shaw *et al.* 2011), Japanese knotweed has since become widespread in much of the UK (Engler *et al.* 2011); it is prevalent in the study region, Cornwall. The ecological traits of Japanese knotweed make it a particularly difficult INNP to control or eradicate. For example, it can regrow from a small fragment of rhizome (Colleran & Goodall 2014), it can grow fast (Beerling *et al.* 1994), and its roots extend far both vertically and horizontally (EA 2013). Ecological risks of Japanese knotweed include outcompeting native plants and changing habitat structure for animals (Engler *et al.* 2011). On domestic property it can have a number of socio-economic risks. For example, it can damage gardens, have a negative aesthetic impact, be costly to eradicate or control, might reduce land / property value, and might cause complications in obtaining a mortgage (RICS 2012; Taylor *et al*. 2013; van Ham *et al.* 2013).

6.2.2 Selection of variables potentially influencing perception of risk

We used factors demonstrated as influencing perceptions of a broad range of environmental risks (e.g. flooding, earthquakes, volcanic eruptions and landslides) to inform those included in the survey that might influence the perception of risk of Japanese knotweed in domestic gardens (Table 6.1); not all of these variables consistently predict perceptions of risk. The perception of risk of Japanese knotweed in domestic gardens was measured as perceived a) frequency of this plant and b) severity of impacts (Kasperson *et al.* 1998).

1. Direct experience

Research suggests that direct experience of a risk will likely result in greater clarity, persistence and strength of perception of that risk compared with indirect experience (Whitmarsh 2008). Here we consider two types of direct experience:

a) *Direct professional experience*: If participants' have or had an occupation where they are more likely to encounter Japanese knotweed. In this study we define two possible categories of such professions: i) working in the housing market sector, including as estate agents, solicitors, architects, building surveyors or mortgage advisors; and ii) work involving ecology, including as ecological consultants, working for a UK environmental / conservation organisation (e.g. Natural England or National Trust), or as an academic whose research involves ecology. All other occupations were grouped as 'other'.
b) *Direct domestic experience*: If participants have or have had Japanese knotweed in the garden of a property they have owned or rented, or on land they have managed.

2. Indirect experience

When people do not have direct experience of an event they base their perceptions of risk on information from secondary sources, for example friends, family or media (Kasperson *et al*. 1998). Mass media has been found to be the most common way of obtaining information on INNP (McNeely 2001). Theoretical and empirical research suggests that when people gain information about a risk from secondary sources, and combine it with perceptions of closely related risks, it can result in social amplification of that risk (Pidgeon et al. 2003). Resulting behavioral responses can have secondary social and economic consequences (Renn *et al*. 1992). Determining whether survey participants who only receive information about Japanese knotweed via the mass media have under- or over-inflated perceptions of risk would help understand if its media portrayal is contributing to social amplification of risk. We define mass media as TV, radio and newspapers.

3. Proximity to risk

If an individual is closer to a risk, either geographically, or in a way that increases their liability to the impacts, the consequences will likely appear greater; in our survey we considered both of these:

a) *Geographically closer:* This was measured in terms of whether participants know of Japanese knotweed within 5km of home, either in a garden or on other land.
b) *Increased liability:* One way in which proximity to the liability of certain risks can increase, and that has been proven in some studies to influence perception of risk, is by owning rather than renting property (Burningham *et al.* 2008; Wachinger *et al.* 2013). The assumption is that if someone owns property they might be more concerned about certain environmental risks as they are usually responsible for resulting economic costs.

4. Socio-demographics

We selected three socio-demographics that are easily and accurately measurable.

a) *Gender:* the socio-demographic variable perhaps most commonly examined as a factor in perception of risk is gender (Slovic 1999), with multiple studies finding that women generally perceive risks as more problematic than men (Flynn *et al.* 1994; Gustafson, 1998; Karanci *et al*. 2005; Barberi *et al*. 2008; Miceli *et al.* 2008; Armaş & Avram 2009; Kellens *et al*. 2011).

b) *Level of education*: Education is also frequently found to be significant in explaining perceptions of risks (Karanci *et al.* 2005, Barberi *et al*. 2008,), with those with lower levels of qualifications usually having greater perception of risk (Armaş & Avram 2009).

c) *Age:* Many studies explore the influence of age, often finding that older people have a higher perception of risk (Kellens *et al.* 2011), however, this is usually a weaker relationship than with other socio-demographic variables (e.g. Karanci *et al*. 2005; Lindell and Hwang 2008; Miceli *et al.* 2008).

6.2.3 Sampling regime

To reduce the biases associated with each in isolation, survey responses were gathered by two methods between July 2014 and February 2015. First, passers-by in Truro city centre, one of the largest urban areas in Cornwall, were asked to participate. Participants were selected at random and those who did not have time to complete the survey were given a flyer promoting the online version. Second, a press release was issued advertising the online version of the survey, in which INNP were not mentioned to avoid creating a bias in participants. Third, participants identified as likely to come across Japanese knotweed in their occupation through online searches (e.g. estate agents) and through email distribution lists, were emailed the link to the online survey. All participants were Cornwall residents.

6.2.4 Survey design

The survey was designed following guidance from Bernard (2011). All questions analysed here were closed, response options to which were randomised where possible. The survey was piloted several times to refine wording and order of questions.

There were three sections in the survey (see Appendix 6.1 for full list of questions). The first asked about perception of risk of Japanese knotweed, split into two questions addressing (1) perception of frequency, and (2) perception of severity of impacts. To put this into context, questions were also asked about perception of risk of other potential concerns on domestic property (ivy, large trees close to the property, gulls, bats, subsidence, damp, flooding, dry rot, mundic [deterioration of concrete structures due to inappropriate materials used], and radon [a natural gas which can have elevated levels inside some buildings and has associated health concerns]). These potential concerns were derived from semi-structured interviews with estate agents (see Appendix 6.2 for details).

The second section focused solely on Japanese knotweed. Participants were asked if they had heard of this INNP. If they answered no, they moved straight to the final section. Questions were asked to determine if participants had had Japanese knotweed on a property they owned or rented, or on land they managed (direct domestic experience). Then two questions were asked to explore perceptions of particular risks (these were compiled based on results from analysis of internet discourse on the subject and semi-structured interviews with housing market professionals, see 6.2 for details). The questions were a) 'what is your perception of the threat posed by the following issues associated with Japanese knotweed in domestic gardens?' And b) 'what would be your primary motivation for taking action to control Japanese knotweed if present in the garden where you currently live?'.

The third section collected background data, including socio-demographics (age, gender, level of education), and asked questions that allowed us to identify whether participants worked in an occupation where they regularly came across Japanese knotweed (direct professional experience).

The sample comprised a marginally lower percentage of women than in the region (49.2% and 51.6% respectively; ONS 2011; Table 6.1). It comprised similar percentages to the region in all age categories: 18-29 age category was 18.5% and 20.7% respectively, 30-39 age category was 18.8% and 16.9% respectively, 40-49 age category was 19.5% and 18.6% respectively, 50-59 age category was 18.8% and 15.4% respectively, and the 60+ age category was 24.3% and 28.5% respectively (ONS 2011). The percentage of participants with the top level of education (first degree or above) was higher than for the region (52.9% and 26% respectively; ONS, 2011). This was skewed by the targeting of participants with professional experience in the housing market and in ecology. A similar percentage of the sample owned property compared with the region (67.2% and 69.6% respectively; ONS 2011).

6.2.5 Analysis

We first determined which factors predicted perception of risk of Japanese knotweed in domestic gardens. Two models were constructed (using R 3.1.3; R 2015) to evaluate the responses to the following questions (1) 'how frequently do you think the following occur on domestic properties in Cornwall?', (2) 'if the following were identified on a property, how severe do you think the consequences could be?'. For each question participants could choose from five levels of response or respond 'no idea / never heard of'. Responses of the last option were excluded from analyses. Explanatory variables included in the maximal models were direct professional experience of Japanese knotweed (three-level fixed factor), direct domestic experience of Japanese knotweed (two-level fixed factor), indirect experience of Japanese knotweed (two-level fixed factor), increased geographical proximity to risk (two-level fixed factor), increased proximity to liability of risk, (two-level fixed factor), age category (five-level fixed factor), education (four-level fixed factor) and gender (two-level fixed factor; Table 6.1). As the response variable was categorical we used cumulative link models using the 'clm' function in the 'ordinal' package (Christensen 2014). To verify whether model results were not due to differences in occupation, models with only participants whose occupation did not involve Japanese knotweed were also constructed.

Following the methods outlined in Grueber *et al*. (2011), we utilised a multi-model inference approach using the 'MuMin' package (Barton 2011) to determine the final averaged model and to evaluate the relative importance of each parameter. All models where ΔAIC <6 were used to produce the averaged model (Richards *et al.* 2008).

We were particularly interested in how direct professional experience of Japanese knotweed influenced perception of risk, as it has been found to be a significant factor explaining perception of INNP more generally (Selge *et al.* 2011; Gozlan *et al.* 2013). To address this, we ran analyses to test whether sub-categories differed in (1) perception of risk relative to other risks on domestic property, and (2) which specific risks concern them most. Averages, standard errors and rankings were calculated for a) each potential risk on domestic property (again, 'no idea / never heard of' responses excluded) and for b) participants' perception of the threat to particular risks from Japanese knotweed ('no idea' responses excluded). The number of participants within each sub-category of direct professional experience (other, housing market and ecology) who listed a particular risk as their primary motivation for taking action to control Japanese knotweed were summed and ranks were calculated.

6.3 Results

In total 329 surveys were completed (144 in person, 185 online).

6.3.1 Predictors of perception of risk

Participants perceived Japanese knotweed to be less frequent on domestic property in Cornwall if their occupation involved the housing market ($p<0.001$, $z = 5.20$), if they did not have domestic experience of Japanese knotweed ($p = 0.006$, $z = 2.74$), if they did not know of Japanese knotweed within 5km of their home ($p = 0.004$, $z = 2.91$), or if they had the top level of education (1st degree or above) ($p = 0.003$, $z = 2.96$; Table 6.2; see Table A6.2 for global models). Education remained significant in the model that only carried out analysis of participants whose profession was ‘other’ (see Table 6.3 for details).

Participants who thought that the consequences of Japanese knotweed being present on domestic property could be more severe had occupations that involved the housing market ($p = 0.020$, $z = 2.322$), knew of Japanese knotweed within 5km of their home ($p<0.001$, $z = 4.928$), or were older (significant age categories were: ‘30-39’ $p = 0.044$, $z = 2.012$ and ‘60+’ $p = 0.006$, $z = 2.736$; Table 6.2; see Appendix 6.4 for global models). The third level of education (‘further education or vocational training’) was marginally significant, however, when a model was constructed using only participants whose occupation was ‘other’, education was no longer significant (see Table 6.3 for details).

Participants whose occupation was ‘other’ ranked their perception of how frequently Japanese knotweed occurs on domestic property in Cornwall as highest (6th) in relation to the other potential concerns on domestic property, followed by participants whose occupation involved the housing market (11th), and participants whose occupation involved ecology ranked it lower (8th; Figure 6.2a). Both participants whose occupation involved the housing market and ecology ranked the potential severity of Japanese knotweed on domestic property higher (4th) in relation to other potential threats, whereas participants whose occupation was ‘other’ ranked Japanese knotweed lower (7th; Figure 6.2b).

6.3.2. Risks of greatest concern to participants

The most common primary motivation given to control Japanese knotweed in domestic gardens by participants whose occupation was ‘other’, or involved ecology, was the potential for it to spread to adjacent land, whereas this ranked second for participants whose occupation involved the housing market (Table 6.3). Participants whose occupation involved the housing market reported their primary motivation to be concern about damage to building structure, which was ranked second by participants whose occupation was ‘other’, and third by participants whose occupation involved ecology.

Participants whose occupation was ‘other’, housing market and ecology all ranked their perception of the threat by Japanese knotweed spreading to adjacent property as the highest (Figure 6.3). Perceptions about the level of threat from other potential risks of ‘devaluing property’ and damage to the structure of the property were ranked much lower by all participants.

6.4 Discussion

This is the first study to investigate the drivers of perception of risk of INNP in domestic gardens, using Japanese knotweed in the UK as a case study. We found large differences in perceived risk of Japanese knotweed depending on people’s profession, their direct domestic experience, their geographical proximity to the risk and socio-demographic differences. Here we consider explanations for these results and discuss the implications for garden management decisions, risk communication, and awareness strategies.

6.4.1 Predictors of perception of risk

Direct professional experience was significant in predicting perception of the frequency of Japanese knotweed on domestic property, as well as perception of the potential severity of consequences. Participants whose occupation involved the housing market perceived the frequency of Japanese knotweed on domestic property as lowest, but perceived the potential severity of the consequences as highest. Housing market professionals are likely to encounter Japanese knotweed on domestic properties if it is present, and therefore are likely to have more accurate knowledge of the frequency with which it occurs therein than other participant groups. This increased likelihood of observing the problems that Japanese knotweed can cause in domestic gardens, including observation of particularly acute impacts, might inflate their perception of severity of risk. The perceptions of those whose occupation involved ecology aligned more closely with participants who had no professional experience of Japanese knotweed. This might be because this subset included participants from professions that would not necessarily involve Japanese knotweed, or require knowledge about its impacts or management. Professional gardeners are also likely to have specialist knowledge about INNP in domestic gardens, however, as we did not specifically target this group, we did not have the sample size to analyse it.

Participants with direct domestic experience of Japanese knotweed or increased geographical proximity to risk, measured as whether participants knew of Japanese knotweed within 5km of their home, perceived its frequency to be higher than those without these attributes. An explanation for this might be because those in these participant groups are more likely to live in areas of locally high abundance of Japanese knotweed, and therefore base their perception of frequency on their local environment. This aligns with a study that found environmental managers made decisions based on local perception of abundance and impacts of INNP (Andreu *et al*. 2009).

Direct domestic experience was not significant in predicting perception of severity, increased geographical proximity to risk was. This could be because the consequences of having direct domestic experience is not sufficiently problematic to inflate perception of risk severity. However, observing Japanese knotweed close to home might inflate perceptions of risk due to concerns about it spreading to a respondent’s property and not knowing the level of management required to control it or the reality of the severity of threat to personal property.

Two socio-demographic factors were significant predictors of perception of risk – education and age. Participants with the highest level of education (first degree or above) had a significantly lower perception of the frequency of Japanese knotweed. The reason for this might be similar as to why domestic experience and increased geographical proximity to risk had a significant effect – that people are basing their perceptions on local conditions. There is evidence to suggest that at a local scale Japanese knotweed is more likely to be present, and more abundant, in areas of greater socio-economic deprivation (chapter two), while it has also been found that individuals from areas of greater deprivation are less likely to attain the highest levels of education (Crawford *et al.* 2012). This covariation makes distinguishing causality difficult.

It is also difficult to determine the causal mechanism underlying the positive relationship between age and perceived severity of consequences. Perhaps it is because with age one accumulates conflicting viewpoints about INNP, which contribute to inflation of perception of risk. Alternatively, it might not be a function of age, but rather experiential and cultural differences between generations (Bremner & Park 2007). Other studies have found education and gender to influence perceptions towards INNP. For example, one study found that older people reported greater support for control and eradication of INNP in Scotland (Bremner & Park 2007). Another study found that older people, and those with higher levels of education were more supportive of higher levels of management intervention of INNP in parks (Sharp *et al.* 2011). Conversely, other research has found that in south-west Spain younger people were more aware of concerns surrounding INNP (García-Llorente *et al.* 2008).

Gender was the only socio-demographic factor that was not significant in predicting perception of risk of either frequency, or severity. Gender may perhaps be more of a factor in emotive decisions such as control / eradication of animals, for example, lethal deer management (Dougherty *et al*. 2003).

Proximity to risk liability, measured by whether people owned property or not, was not significant in predicting either perceived frequency or severity of risk. Perhaps this is because attitudes to dwellings are governed more by a sense of belonging, rather than legal ownership in itself. Furthermore, property renters and owners observe similar impacts, at a similar frequency, and receive information from similar channels.

Additionally, whether participants had heard about Japanese knotweed only via mass media was not significant in predicting perceived frequency and at most only had a minor effect on perception of severity (see Table A6.5). Several studies have found a limited ability of the mass media to influence perception of other risks (Freudenburg *et al.* 1996; Wåhlberg & Sjöberg 2000; Brenkert-Smith *et al*. 2013), as well as support for management options of invasive species (Sharp *et al.* 2011). Despite sensationalist headlines, pictures and loaded language, factual information is contained within some articles (Freudenburg *et al.* 1996), which may help objectively to assess the risk.

Furthermore, perhaps many doubt the credibility of some media (Sjoberg 1999), so do not base their perception of risk on it. Alternatively, it may be that other complex social processes and interactions are also producing social amplification of risk, for example, information through social networks (e.g. friends and family) or internet based information.

6.4.2 Risks of greatest concern to participants

Concern about spread to adjacent land was reported as the top motivation for controlling Japanese knotweed in domestic gardens by all participant groups except those whose occupation involved the housing market, who ranked it second. Similarly, perception of the threat from Japanese knotweed spreading was ranked top by all participant groups. This is perhaps an indication of the high level of concern regarding the uncontrollability of the plant, and the consequences of not only having to control it on your land. For example, in the worst case scenario, spread to adjacent land could result in legal proceedings.

Damage to the structure of a property was rated as the second highest motivation to control Japanese knotweed in a domestic garden both by participants whose occupation involved ecology, as well as those who had no professional experience of Japanese knotweed. Interestingly, however, both participant groups rated their perception of risk of this threat as relatively low. A number of factors might have influenced this. First, perhaps people perceive this threat as one they can realistically mitigate, therefore are perhaps more likely to take preventative action if required. Second, perhaps people perceive the consequences of this threat as high, which is a reason to act to prevent it, even if the likelihood of it occurring is low. Lastly, perhaps the scientific uncertainty of this risk manifests as conflicting information, which along with variation in interpretation and communication of this risk by different secondary sources, might subsequently influence how people perceive the risk. In depth interviews could provide insight into why people develop these perceptions of these risks.

6.4.3 Conclusions

When interpreting the results of this study it is important to acknowledge that simply because a hazard is perceived to be a risk, it does not necessarily follow that the details of the risk are understood (Clayton & Myers 2009), or that perceptions logically correlate with attitudes and behaviour. There are likely to be many other factors, such time and money availability, impacting these complex relationships (Wåhlberg & Sjöberg 2000; Wachinger *et al*. 2013). The extent to which perceptions of risk are based on values influences how difficult conflicts arising from different perceptions are to resolve (Estévez *et a*l. 2014). Furthermore, the lack of scientific consensus about how to control Japanese knotweed, or if it should always be controlled (Delbart *et al.* 2012), is likely contributing to the large variation in perceptions of risk about this plant in domestic gardens, even amongst those who encounter it in a professional context.

As perceptions of risk are important in determining what, if any, action is taken to manage INNP on domestic property, the results of this paper have several important implications. The results highlight the need for discourses communicating the risks of INNP in domestic gardens to be clear and accurate. This could be achieved by clarifying terminology used and concepts discussed (Selge *et al*. 2011), by providing balanced discussion of the risks, impacts and solutions, and highlighting the role and responsibility those managing INNP in domestic gardens have. As media publications cannot be fully regulated, it is particularly important for government organisations carefully to consider risk communication strategies. Furthermore, the drivers of risk perception identified in this study could be used to target awareness campaigns to reduce over or under-inflated risk perceptions developing. Implementation of these recommendations could help reduce the ecological and socio-economic impacts of INNP in domestic gardens, as well as the wider environment.

Table 6.1 Summary of variables chosen *a priori* that might be influencing perception of risk of INNP on domestic property.

Variable	Levels of variable
DIRECT EXPERIENCE	
1. Direct professional experience	If occupation involves the housing market
	If occupation involves ecology
	Occupation = other
2. Direct domestic experience	False
	True
INDIRECT EXPERIENCE	
1. Heard only from mass media	False
	True
PROXIMITY TO RISK	
1. Geographical: If know of Japanese knotweed within 5km of home	False
	True
2. Liability: If own property	False
	True
SOCIO-DEMOGRAPHICS	
1. Gender	Female
	Male
2. Level of education	1: 'O' level, GCSE, or equivalent or less
	2: 'A' Level, AS Level, or equivalent
	3: Further education or vocational training
	4: First degree or higher
3. Age category	18 – 29
	30 – 39
	40 – 49
	50 – 59
	60 +

Table 6.2 Results from 'cumulative link models' of factors influencing a) how frequently people thought Japanese knotweed occurred on domestic property in Cornwall and b) how severe people thought the consequences of having Japanese knotweed on domestic property in Cornwall could be.

Variable	Estimate	Standard error	Adjusted SE	Z value	Significance	Relative importance
a)						
1|2	-3.569	0.496	0.497	7.179	***	
2|3	-1.888	0.449	0.450	4.196	***	
3|4	0.057	0.426	0.427	0.133		
4|5	1.638	0.425	0.427	3.841	***	
Direct professional experience (occupation involves ecology)	-0.461	0.320	0.321	1.434	NS	1.00
Direct professional experience (occupation involves housing market)	-1.724	0.331	0.332	5.193	***	
Direct domestic experience (true)	0.899	0.327	0.329	2.736	**	0.98
Indirect experience: if heard only from mass media (true)	-0.393	0.350	0.351	1.119	NS	0.39
Proximity to risk: know Japanese knotweed within 5km (true)	0.669	0.229	0.229	2.913	**	1.00
Proximity to risk: if own property (yes)	-0.107	0.254	0.255	0.419	NS	0.26
Education (level 2)	-0.652	0.468	0.470	1.387	NS	0.78
Education (level 3)	-0.709	0.375	0.377	1.881	NS	
Education (level 4)	-0.974	0.327	0.329	2.963	**	
Gender (male)	-0.342	0.223	0.224	1.529	NS	0.53
					NS	

b)						
1|2	-1.744	0.460	0.461	3.784	***	
2|3	-0.001	0.425	0.427	0.002	NS	
3|4	1.236	0.440	0.441	2.803	**	
4|5	2.321	0.461	0.462	5.019	***	
Direct professional experience (occupation involves ecology)	0.414	0.326	0.327	1.265	NS	0.76
Direct professional experience (occupation involves housing market)	0.743	0.319	0.320	2.322	*	
Direct domestic experience (true)	0.292	0.323	0.325	0.901	NS	0.33
Indirect experience: if heard only from mass media (true)	0.570	0.350	0.352	1.622	NS	0.57
Proximity to risk: know Japanese knotweed within 5km (true)	1.163	0.235	0.236	4.928	***	1.00
Proximity to risk: if own property (yes)	0.455	0.287	0.288	1.578	NS	0.57
Gender (male)	-0.339	0.234	0.235	1.443	NS	0.49
Education (level 2)	-0.209	0.438	0.439	0.475	NS	0.54
Education (level 3)	0.675	0.376	0.377	1.790	NS	
Education (level 4)	-0.054	0.323	0.324	0.166	NS	
Age (30-39)	0.747	0.370	0.371	2.012	*	0.36
Age (40-49)	0.742	0.381	0.382	1.940	NS	
Age (50-59)	0.735	0.399	0.400	1.835	NS	
Age (60+)	1.076	0.392	0.393	2.736	**	

Significance codes: < 0.001 ‘***’ < 0.01 ‘**’ < 0.05 ‘*’, NS = non-significant

Table 6.3 Response to the question: 'What would be your primary motivation for taking action to control Japanese knotweed if present in the garden where you currently live?' (Participants could only select one answer).

Primary motivation	**Occupation = other**	**Rank**	**Occupation involved housing market**	**Rank**	**Occupation involved ecology**	**Rank**
Concern it will spread to adjacent land	63	1	12	2	20	1
Concern about damage to structure of the house	38	2	13	1	8	3
Concern about negative impacts on other plants	38	2	2	6	9	2
Concern it will devalue the property	18	4	10	3	5	5
Concern about potential future expenses	10	6	4	4	6	4
Concern about damage to structure of the garden	12	5	2	6	2	6
Concern about negative impacts on animals	9	7	0	9	2	6
Other	5	9	3	5	2	6
I would have no motivation to take action.	6	8	2	6	0	9
It looks unsightly	2	10	0	9	0	9

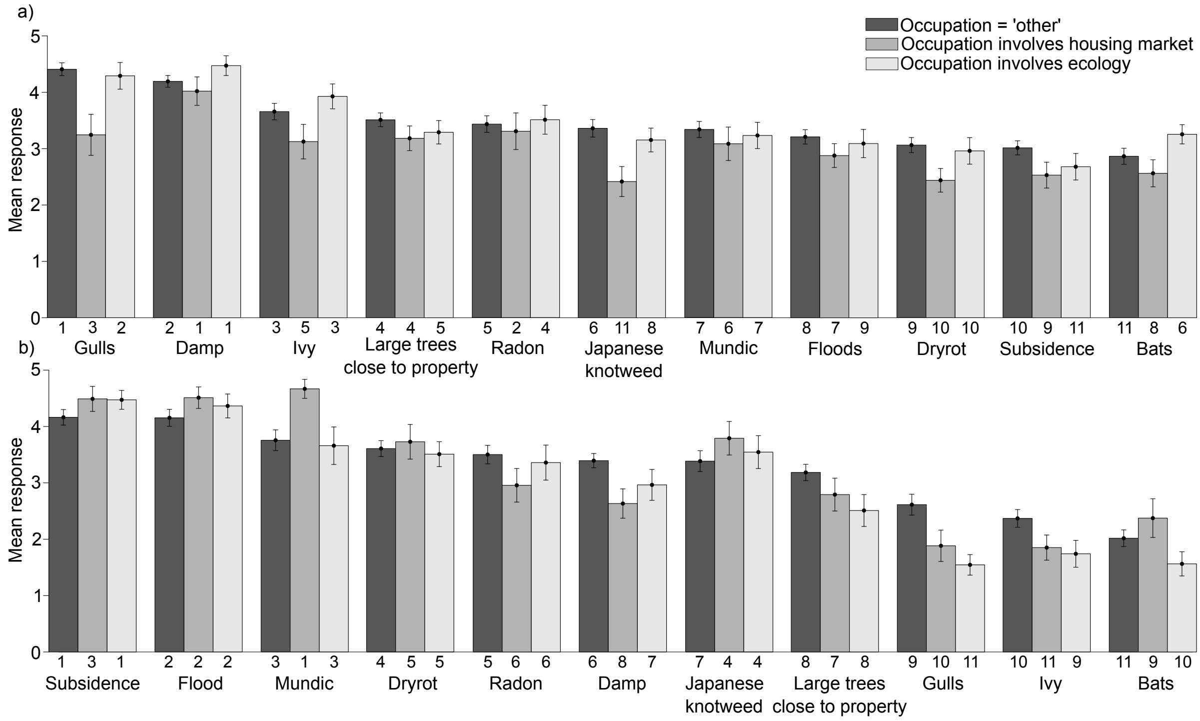

Figure 6.1 Participants' responses to a) how frequently people thought Japanese knotweed occurred on domestic property in Cornwall and b) how severe people thought the consequences of having Japanese knotweed on domestic property in Cornwall could be. Response 'no idea / never heard of' excluded. Numbers represent the rank.

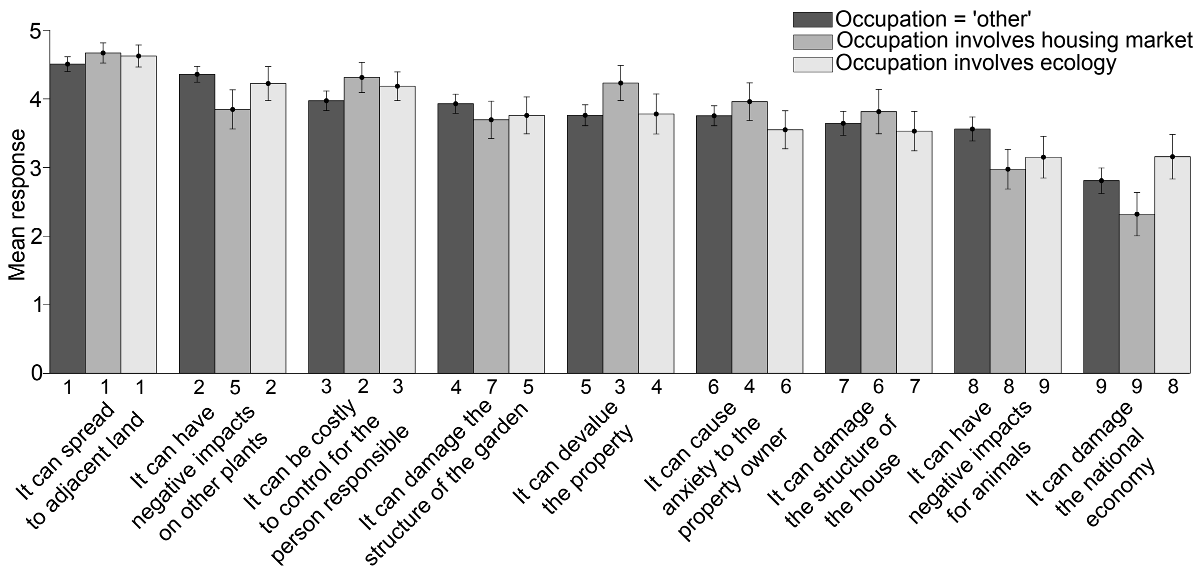

Figure 6.2 Survey participants' response to the question 'What is your perception of the threat posed by the following issues associated with Japanese knotweed in domestic gardens?' Response 'no idea' excluded. Numbers represent the rank.

Chapter seven

This thesis thus far has focused on the processes that spread INNP in a human-dominated landscape. As INNP spread, so do the ecological and socio-economic impacts they can have. The details of the economic risks that INNP pose within domestic gardens is poorly understood. Chapter seven assesses the magnitude and frequency of the economic challenges Japanese knotweed poses within domestic gardens, and compares these with associated public perceptions. Further understanding of this topic will assist in more accurate knowledge of the extent of impact, assessment of economic risks for individuals, designing risk communication strategies and informing the level of intervention and assistance required from government authorities.

Chapter 7:
Robinson BS, Inger R, Gaston KJ. Impacts of invasive non-native plants on domestic properties.
This chapter has been written for BioScience.

Author contributions
I led the development of the idea for this chapter, designed the structured questionnaire, collected the majority of questionnaire responses, carried out all semi-structured interviews, conducted the analyses, and wrote the manuscript.

Impacts of invasive non-native plants on domestic properties

Abstract

As a key driver of environmental change, invasive non-native plants (INNP) are of significant global concern. Domestic gardens are recognized as notable sources of INNP, particularly in urban settings, and are one of the commonest contexts in which the public encounter INNP. However, the challenges they pose in this setting are poorly understood. Highlighting the public's role in controlling INNP in domestic gardens, we critically assess the magnitude and frequency of the economic challenges they pose, and associated public perceptions. Using the case study of Japanese knotweed in the UK, where it is a highly problematic INNP, we find that the magnitude and frequency of the risks it poses in domestic gardens are much lower than anticipated based on media coverage, and compared with public perception. We discuss the implications of these findings for management of domestic gardens, the biodiversity and wellbeing benefits they can provide, and communication of INNP risks.

7.1 Introduction

Invasive non-native plants (INNP) are a major component of global environmental change (CBD 2010; Hulme *et al*. 2013). Whilst INNP vary greatly in the risks they pose, some can have serious adverse impacts on biodiversity and ecosystem services with potentially significant negative economic and human wellbeing consequences (Pejchar & Mooney 2009; Vilà *et al.* 2011). The spread of INNP, and therefore the associated risks and impacts, will likely increase as globalisation, global trade and travel networks and volumes also grow (Banks *et al.* 2014).

The risks posed by, and the impacts of, INNP are typically evaluated for particular sectors, usually commercial, such as agriculture, forestry and fisheries (Pimentel *et al*. 2005; Pimentel 2009; Holmes *et al.* 2009; Vilà *et al*. 2010). For instance, the invasive weed yellow starthistle *Centaurea solstitialis,* in California, USA, resulted in economic losses calculated at US$7.65 million annually due to reduced livestock forage value, and control costs for ranchers of US$9.45 million (Eagle *et al*. 2007). Non-commercial risks and impacts are usually determined at the national or regional level, for concerns such as restrictions to recreational activities, decreases in carbon sequestration, changes to soil stabilization and disease regulation (Pejchar & Mooney 2009). For example, the prolific growth of Tamarisk *Tamarix spp.,* in the US restricts the holding capacity of streams, subsequently increasing flood risk, and resulting in estimated damages of US$52 million annually (Pejchar & Mooney 2009).

In much of the world one of the commonest contexts in which members of the general public will encounter INNP is in their own domestic garden (Qvenild *et al.* 2014). However, the details of potential risks posed by, and impacts of, the presence of INNP in these settings, and the consequences for those responsible for their management, have received little research attention (but see McDermott *et al*. 2013 and Qvenild *et al*. 2014). Those studies that exist have largely concerned the impacts of INNP escaping into the wider landscape (Groves *et al*. 2005; Smith *et al.* 2006; Dehnen-Schmutz *et al.* 2007b; Qvenlid *et al.* 2014), rather than INNP invading into domestic gardens and the impacts they can have therein.

This said, in addition to the detrimental impacts on biodiversity and ecosystem services, the financial costs and anxiety levels incurred when INNP are present in domestic gardens can be high. Financial costs can often include herbicides, hiring contractors, specialist equipment (e.g. herbicide sprayer), waste disposal of plant material, and time and labor (McDermott *et al.* 2013). Individuals responsible for controlling INNP in domestic gardens are not usually obliged to do so unless there is spread onto neighbouring land. If INNP do spread between domestic gardens there is potential for civil disputes to arise between neighbors, which on occasion could escalate into legal proceedings (van Ham *et al.* 2013), and therefore potentially additional expenses and anxiety. Furthermore, some INNP are reported to impact property prices when on or near the property (Olden & Tamayo 2014).

In domestic gardens, it is the owner (or perhaps tenant) who is largely responsible for managing INNP and paying any costs incurred (Qvenild *et al.* 2014). Therefore, when exploring the risks and impacts of INNP in domestic gardens it is important to consider public perceptions and social context, as these can influence management decisions, management success and risk mitigation behaviour (Kapler *et al.* 2012; Estévez *et al.* 2014). However, studies on perceptions of INNP tend to focus on opinions of conservation professionals (e.g. Gozlan *et al.* 2013), horticultural professionals (e.g. Humair *et al.* 2014) and commercial or experienced land managers (e.g. woodland owners; e.g. Kapler *et al*. 2012). Studies exploring public perceptions of INNP more broadly tend to focus on their impacts in the wider environment, often focusing on ecological impacts (e.g. García-Llorente *et al*. 2008; Gozlan *et al.* 2013) and management approaches (e.g. Bremner & Park 2009; Selge *et al*. *2011).*

Public perception of risk is complex and multifaceted. People will form an opinion based on direct experience, indirect experience, or a combination. When direct experience of a risk is low the majority of people derive information and form their opinion based indirect or secondary sources, mainly media and informal sources, e.g. friends and family (Kasperson *et al.* 1998). Interactions between these indirect sources, the way people interpret such information and previous relevant experience and knowledge of the risk, or closely related risks, are thought sometimes to cause social amplification of the risk (Pidgeon *et al*. 2003). This can manifest itself in resulting actions taken

(Kasperson *et al.* 1998). One frequently cited example of social amplification of risk is that associated with genetically modified foods in the UK (Frewer *et al.* 2002).

If social amplification of risk is occurring with INNP in domestic gardens, one of the secondary effects could be to exacerbate variation in how such plants are managed there. Furthermore, if the presence of INNP in domestic gardens is perceived as too much of a burden, it may lead to domestic gardens themselves becoming undesirable resulting in decisions made and actions taken to minimise required management. This would add to an increasing number of pressures on urban green spaces. It could have negative implications for the often undervalued biodiversity, ecosystem services and human wellbeing benefits that domestic gardens can provide in many westernized temperate (and typically heavily urbanized) regions (Gross & Lane 2007; Goddard *et al.* 2010; Gaston & Gaston 2011; Lerman & Warren 2011; Qvenlid *et al.* 2014). Domestic gardens make a significant contribution to urban biodiversity, and therefore ecosystem services, as they often provide a high proportion of urban greenspace and connect otherwise fragmented urban landscapes (Gaston *et al*. 2005; Davies *et al.* 2009; Gaston & Gaston 2011). In the UK, for example, domestic gardens cover >20% of land area in many cities (Loram *et al*. 2007). Increasing urbanization will increase the area of land covered by domestic gardens. Many important human wellbeing benefits from domestic gardens have been documented, including increased physical and mental health (Freeman *et al*. 2012), 'escapism' (Gross & Lane 2007), providing a space for leisure and social activities (Bhatti & Church 2004), connectedness with nature (Restall & Conrad 2015), and creating opportunities to share and gain ecological knowledge and skills (Barthel *et al.* 2010). Domestic gardens are particularly significant in mitigating general decreases in the access of urban residents to nature (Freeman *et al.* 2012). The potential ways that direct and indirect experience might influence opinion forming, action planning and decision making in relation to INNP in domestic gardens are shown in Figure 7.1.

Further understanding of the risks posed by INNP in domestic gardens will assist in more accurately accounting for their full impact (Pejchar & Mooney 2009), assessing economic risk for individuals, planning the appropriate level of investment in management, designing risk communication and guiding the required level of intervention and assistance from environmental authorities. In this paper we explore the magnitude and frequency of economic challenges presented by INNP on domestic properties and associated public perceptions. Japanese knotweed *Fallopia japonica* in the UK is used as a case study as it provides a valuable example of many of the key issues. First, we outline the background to the concerns around this species. Second, we explore a series of linked questions about perceptions and knowledge of Japanese knotweed in domestic gardens and particular problems that have been encountered, then we provide evidence derived from a multi-method approach to address them. We discuss the broader relevance of this study for Japanese knotweed in other countries, and for other INNP in domestic gardens.

7.2 Japanese knotweed in the UK

Japanese knotweed is a herbaceous perennial (see Bailey *et al.* 2008 for detailed discussion of taxonomy) that was introduced into the UK in the mid-1800s as an attractive garden addition (Bailey & Conolly 2000), where its reproduction is thought to be almost entirely clonal (Bailey *et al*. 2008). It has since become widespread there, as well as in many parts of Europe and North America (Beerling *et al.* 1994; Engler *et al.* 2011). It causes ecological damage by outcompeting native plants, including via allelopathy (Dommanget *et al.* 2014).

Japanese knotweed can regenerate from a small fragment of rhizome (Sásik & Eliáš 2006), grows fast (Beerling *et al*. 1994) and can have roots up to 2 m deep and 7 m horizontally (EA 2013). These traits make management difficult, particularly in domestic gardens where those responsible often do not have the specialist knowledge or equipment needed effectively to control/eradicate it. Low levels of Japanese knotweed identification skills amongst the public (by one estimate, <20% of people could identify the species; Chapter four) raise concerns that it might often go unnoticed in domestic gardens, thereby decreasing opportunities for early eradication.

As well as being problematic to manage, Japanese knotweed can cause additional problems for property owners, as its immediate presence or presence on adjacent land might devalue the property or make it difficult to sell (RICS 2012; Taylor *et al*. 2013). These concerns can be traced back to the 1930s, when it was reported that the presence of Japanese knotweed could devalue house prices in East Cornwall by £100, equivalent to £5,668.95 today (Bailey & Conolly 2000). More recently this perception has become more apparent in the media, often with sensational headlines:

1. "Japanese knotweed invasion causes Hertfordshire home price drop" (www.bbc.co.uk/news 2011).
2. "Couple are forced to demolish their £300k four-bed home after it was invaded by Japanese knotweed" (www.dailymail.co.uk 2011).
3. "Japanese knotweed: the scourge that could sink your house sale" (www.guardian.com 2012).
4. "Family finds house's value has halved after Japanese knotweed takes over garden" (www.itv.com/news 2014).

The first and second examples report that a property in England was devalued from £305,000 to £50,000 due to the problems caused by Japanese knotweed. The third is about a sale that fell through when the buyers pulled out because Japanese knotweed was found in the garden. The fourth is part of a series of media stories about a property in south Wales that was supposedly devalued considerably due to the presence of Japanese knotweed on adjacent unregistered land; subsequent reports, indicate that the situation was not as bad as first thought (e.g. www.knotweedservices.co.uk/japanese-knotweed-swansea/).

Japanese knotweed on a domestic property or adjacent land may also impact the willingness of banks and building societies to lend on such properties (Williams *et al.* 2010; RICS 2012). Again, stories about such concerns are not uncommon in the media. Headlines include:

1. "Homeowner turned down for mortgage due to Japanese Knotweed in garden" (www.telegraph.co.uk 2010).
2. "Japanese knotweed invasion is halting house sales as buyers are denied mortgages on blighted properties" (www.dailymail.co.uk 2013).
3. "Banks pull plug on mortgages after discovery of Japanese knotweed" (www.standard.co.uk 2013).
4. "Can Japanese knotweed kill a mortgage deal?" (www.homesandproperty.co.uk 2014)

As the media can both reflect public opinion as well as influence it (Boykoff & Rajan 2007), this increased media coverage of Japanese knotweed in domestic gardens in the UK is likely closely linked to public interest in the matter. This is supported by an analysis of the number of times that the search term 'Japanese knotweed' has been entered into Google, which has increased from 2004 to present (Figure 7.1; Google Trends 2015).

There are a number of pieces of legislation relevant to Japanese knotweed on domestic property in the UK. The dominant two have been The Wildlife and Countryside Act (1981) under which it is 'an offence to plant or cause Japanese knotweed to spread in the 'wild' and The Environmental Protection Act (1991) which dictates that any waste material containing Japanese knotweed is classified as 'controlled waste' (Mantzou 2008; EA 2013).

More recently, several new relevant pieces of legislation have come into effect. Recent changes to the Anti-social and Behaviour Act (2014) mean that this can be used against people not controlling Japanese knotweed in their gardens, when it is having a detrimental effect of a 'persistent or continuing nature on the quality of life of those in the locality' (Home Office 2014). The Infrastructure Act (2015) grants environmental authorities power to enter into 'species control agreements' with owners or managers of domestic gardens, and failure to adhere to these can result in a 'species control order' being issued. Failure to comply with either of the above risks imprisonment, a fine, or both (Infrastructure Act 2015).

7.3 Questions and evidence

Multiple data collection methods were employed during summer 2014 to address a series of questions about the relationship between the general public and Japanese knotweed (an indication is given in Figure 7.1 as to how these, and their findings, fit into that framework). These included surveys, semi-structured interviews, expert elicitation of key actors in the housing market, and searching archival data. Data collection was focused on Cornwall, a county in the South West of the UK, ~3,500km^2 in area. Japanese knotweed is widespread in Cornwall, and this is expected to be an area in which it is particularly problematic.

Question 1: What are levels of public awareness, depth of knowledge and perceptions of risk about Japanese knotweed on domestic property?

Gozlan *et al.* (2013) found that 46% of a sample of the UK public perceived Japanese knotweed to be an ecological threat. There has, however, been no evidence with which to evaluate public awareness, knowledge and perceptions of the potential risks caused by the presence of Japanese knotweed on domestic property, such as whether they perceive it to be a problem and reasons they might be concerned. A survey was used to obtain data on these issues. Responses were gathered between July and December 2014 from Cornwall residents in Truro city centre (the county town of Cornwall), and a reasonably representative socio-economically mixed grouping (153 participants). Additionally, those who could not complete the survey at that moment were given a link to an online version, which was also promoted via a press release (72 participants). For a summary of socio-demographic attributes of participants see Appendix 7.1.

10.7% of participants had not heard of Japanese knotweed. This finding is similar to that of a study in Colorado that found that while 12% of the public had not heard or read about INNP far fewer had heard about specific local INNP (Daab & Flint 2010). Of participants who had heard of Japanese knotweed, self-reported levels of knowledge were mixed, with most participants having intermediate knowledge levels (27.9%; Figure 7.3).

Perception of risk was assessed using the widely used combination of perception of frequency of risk and perception of potential severity of risk (Kasperson *et al.* 1998). 38.7% of participants thought Japanese knotweed would occur 'frequently' or 'very frequently' on domestic properties in Cornwall (Figure 7.4a). Most participants thought that if Japanese knotweed was identified on a property the consequences could be severe, with 42.4% choosing the top two levels of severity (Figure 7.4b).

The majority of participants thought it would be very difficult to control Japanese knotweed (Figure 7.5). The most frequently reported motivation to control/eradicate Japanese knotweed was 'concern it will spread to adjacent land' (31.3%; percentages are calculated only from participants who had heard of Japanese knotweed; Figure 7.6).

This possibly reflects the legal and financial implications, or even concerns about encroachment from neighboring properties as a result of inaction by others.

As awareness, depth of knowledge and perceptions are likely to influence garden management decisions, participants who had heard of Japanese knotweed were asked questions on this topic. When asked what they would do if they had Japanese knotweed in their garden, 47.3% of participants selected 'employ professional help', 33.8% 'treat it themselves', and 15.4% selected the 'other' option. The decision as to whether to employ professionals is dependent on a number of variables, for instance the individuals' expertise in controlling INNP, available finance and time, and the extent of Japanese knotweed. Although only a small percentage of participants (3.5%) said they would 'do nothing', this is still concerning, as it increases the potential for the plant to spread to adjacent land and cause further problems. Of course, even if people recognize the threat from INNP and want to take action, it doesn't necessarily follow that they will do so. There remains an 'intention-behavior gap', which might be influenced by additional factors such as time pressure and other priorities (Hu & Gill 2015).

Participants were asked "If you found a property to buy that was near perfect but had Japanese knotweed in the garden, would you continue with the purchase?". For 20.4% it was not a problem at all. For others (23.4%), it was a reason not to buy the property; the most frequent reasons given being that it was thought to be too much of a problem and too expensive to deal with (Table 7.1). The majority of participants answered that they would buy the property 'under certain conditions' (34.8%). The most common condition given was that work had already begun to clear the plant. 21.4% responded that they did not know enough to answer this question.

Question 2: Where do people obtain information about Japanese knotweed?

Knowledge about INNP might be based on direct experience, however, if direct experience of Japanese knotweed is low, information will largely be based on indirect experience obtained from secondary sources. Such secondary sources might be either informal (e.g. friends, neighbors), or more structured (e.g. media). Previous research indicates that some secondary information sources have the potential to cause social amplification of risk of environmental issues (Frewer *et al*. 2002). Conversely, indirect experience (secondary sources) could in some cases be more objective and reliable than direct experience. Understanding which sources are most important can assist in informing design and dissemination of risk communication messages.

Participants in the aforementioned survey reported hearing about Japanese knotweed through a diverse range of channels, the most frequent being 'word of mouth' (53%; Figure 7.7). These less formal informational sources are likely to reach a broad audience and to be more personalized (Brenkert-Smith *et al*. 2013). However, pooling responses that could be considered 'mass media' - newspapers, television and radio - more participants heard this way than through other channels (59.7%). This is consistent with an earlier study that found media to be the main informational source for INNP for the public (McNeely 2001).

Question 3: How common is Japanese knotweed on properties bought and sold?

Despite increasing reference to Japanese knotweed in the media (Shaw *et al.* 2014), and therefore likely increased societal awareness, it remains unclear how prevalent it actually is in domestic gardens in the UK; direct surveys are challenging because of difficulties of gaining access to domestic gardens. A greater understanding of its prevalence would help estimate the level of risk it poses, design risk communication, and plan appropriate investment in mitigation strategies.

We determined the prevalence of Japanese knotweed on domestic properties or on adjacent land, bought and sold within Cornwall over the past five years. Two methods were used. First, semi-structured interviews were conducted with estate agents or realtors, either in person (n = 18), by phone (n = 5) or email (n = 1). Realtors were located in six different towns and villages throughout west Cornwall. In the majority of cases a senior agent was interviewed. Questions were phrased so as not to be leading or directional (Bernard 2011; see Appendix 7.2 for details). Realtors reported that out of 13,250 domestic properties sold in Cornwall over the past five years, 0.33% (n = 44) had Japanese knotweed on the property or adjacent land (see Table A7.1 for details). Only

0.03% (n = 4) of properties were reported as being devalued (the amount by which is unknown as it is difficult to quantify) and 0.05% (n = 6) reportedly had a delay in the sale due to the presence of Japanese knotweed.

Before purchase most buyers in the UK will choose to, or if they need a mortgage will be required to, have a professional survey conducted to check for undisclosed or unknown problems with a property. To gather data about the prevalence of Japanese knotweed in such surveys on domestic properties building surveyors were contacted. Two responded, the first provided access to electronic versions of building survey reports, a systematic search of which found that 0.35% of domestic building surveys over the past five years had identified Japanese knotweed (no sample size can be provided for data protection reasons, but was a matter of many 100s). The second estimated that no more than 3-4% of domestic building surveys they had carried out over the past five years found Japanese knotweed.

This evidence suggests the prevalence of Japanese knotweed on properties bought and sold within Cornwall was lower than anticipated from its portrayal in the media. The similarity between data from realtors and building surveyors strengthens their internal validity.

Question 4: What consequences does the presence of Japanese knotweed have for securing a mortgage?

If Japanese knotweed is present on, or on land adjacent to, a property for sale in the UK there are concerns it could have consequences for the buyer's chances of obtaining a mortgage on that property (Williams *et al.* 2010; RICS 2012). Despite extensive media coverage of this topic, it remains unclear how likely this actually is. To explore this, two types of data were collected. First, helplines of high street banks, and therefore a sample of the most common mortgage providers in the UK, were contacted (n = 9). They were asked if they would provide a mortgage for a hypothetical situation where a first time buyer was interested in purchasing a property that had Japanese knotweed in the garden. 33% of helplines said they would *not* do so under any circumstance. The others expressed varying requirements about guarantees needed and how in the majority of cases it was at the discretion of the individual employee who visited to value the property. Second, Cornwall-based mortgage advisors identified through internet searches were emailed and asked about mortgages they had processed that had been refused because of Japanese knotweed. These (n = 5) reported that out of 3715 mortgage applications within Cornwall 0.13% (n = 5) were refused over the past five years due to the presence of Japanese knotweed on the property or on adjacent land. One of these was renegotiated when a treatment plan was put in place. The others received offers from alternative mortgage companies, but some individuals pulled out of the sale regardless.

Results suggest that overall very few properties are refused mortgages due to Japanese knotweed, and that the success of obtaining a mortgage on such a property is dependent on a) the bank / building society employed, and b) the individual carrying out the assessment. The lower occurrence of Japanese knotweed in mortgage applications than on properties brought and sold in Cornwall could perhaps be an indication that properties with Japanese knotweed on are more likely to be cash sales.

Question 5: What are the costs involved in controlling/eradicating Japanese knotweed on domestic property?

If Japanese knotweed is present on or adjacent to domestic property being sold in the UK it is likely that eradication or control may be required to reassure the buyer. If a mortgage is required, it is likely that a long-term control/eradiation plan, implemented by professionals along with a finance plan, will be necessary (RICS 2012). The cost will be dependent on the extent of Japanese knotweed and the method chosen. For example, the seller may decide to manage it with or without professional assistance; spray it with herbicide or cut it down (or a combination); and dispose of waste material on or off site. When taken off site there can be disposal costs at landfill sites if a contractor is disposing of it, however, this is not always the case when a member of the public is doing so. The costs might be paid by the seller, the buyer, or by compromise between the two. One large nationwide control company estimated that they receive up to 30 to 40 calls a day (depending on the time of year) and receive up to 6000 visitors to their website a month regarding Japanese knotweed on domestic property (M. Thompson, Environet, pers. comm.).

A variety of estimates of potential costs of control/eradication of Japanese knotweed have been reported. Examples in mainstream UK newspapers include, at the lower end one quote of £1,200 (www.guardian.com 2012), and at the upper end quotes of "up to £20,000" (www.dailymail.co.uk 2013) and £25,000 (www.dailymail.co.uk 2011). Guidelines produced by the Royal Institute of Chartered Surveyors (2012) estimate that the cost of professionally clearing Japanese knotweed from a domestic property typically ranges from £2,000-5,000. They outline the full extent of costs of a particularly bad case on a typical three-bedroom semi-detached property that could accumulate to £15,413 plus 20% VAT; this includes drain replacement, new patio, new greenhouse, part fence replacement, new garage, treatment costs, and legal and professional fees. The guidelines highlight that most cases rarely amount to this much and can be controlled without excessive cost. Estimates of the cost of controlling/eradicating Japanese knotweed using different methods in the scientific literature (Mantzou 2008) are herbicide: £3-8 per m^2, excavation and spreading on site: £15-20 per m^2, excavation and burial on site: £30-40 per m^2, and excavation and removal from site: £150-350 per m2.

We added to these estimates by gathering data on the cost of control by professional contractors. We emailed those listed on the Cornwall Council website that have completed a training course in controlling/eradicating Japanese knotweed. The average cost of treating Japanese knotweed in a typical medium sized garden reported (n = 6) was £205.50 (incl. 20% VAT; s.e. = 24.53) per year, and takes typically 3-5 years. Therefore, the total costs range from £615-1,025. 83.3% (n = 5) of contractors did not offer a guarantee, a decision justified because of difficulty in confirming complete eradication. One large nationwide control company estimated treatment costs are typically around £3,725 plus 20% VAT (M. Thompson, Environet, pers. comm.), which includes an insurance backed five-year guarantee. Estimates of the cost of Japanese knotweed disposal at a landfill site were obtained from a waste disposal company based in Cornwall (Table 7.2).

The control / eradication estimates we collected were low compared to those reported in the media and in the majority of cases likely to be a small percentage of the value of a property. However, estimates collected here don't account for potential additional costs, such as replacing damaged structures (e.g. walls) and possible legal fees, which could amount to a large sum. The costs involved in clearing Japanese knotweed from a domestic garden are clearly very much case dependent.

7.4 Conclusions

INNP can have widespread and serious ecological and economic impacts, however little research has been done in domestic gardens despite this being one of the most common places they are encountered (Qvenild *et al.* 2014). Using a multi-method approach, this study collated evidence to evaluate the magnitude and frequency of economic challenges presented by INNP in domestic gardens and associated public perceptions, using Japanese knotweed in the UK as a case study.

We found that the magnitude and frequency of the risks posed by Japanese knotweed in domestic gardens were much lower than anticipated based on media coverage, and compared to the public's perception based on responses to our survey. Heightened risk perceptions around this and other INNP could have several consequences. They could result in unnecessary control actions being taken to minimise domestic garden management in response to INNP presence or potential presence, such as paving over some or all of the domestic garden. Such actions have the potential to reduce the wellbeing, biodiversity and ecosystem service benefits that domestic gardens provide. Such impacts could become more acute under the large predicted increases in urbanization globally (UN 2010), as gardens become the primary source of access to nature for an increasing proportion of society (Freeman 2012). Furthermore, heightened risk perceptions might also make people less likely to report INNP generally and, perhaps, more likely to conceal them. This would be detrimental to efforts to monitor, track and initiate early identification and control efforts of INNP. Conversely, if (i) risks are perceived as very low, (ii) people do not know about INNP, and (iii) they cannot identify INNP, the consequences could be similar.

Given that Japanese knotweed in domestic gardens *can* result in high costs and levels of anxiety, can have detrimental ecological impacts, and will continue to spread between gardens and from gardens to the wider environment if left unmanaged or is mismanaged, it is important control/eradication efforts continue. To maximise efficiency and minimise costs this will be best done via an integrated landscape scale approach, involving private and public landowners. Intervention from authorities may be needed to assist with controlling INNP in areas where resources are limited. However, current austerity measures could mean that local authorities have to make difficult decisions about prioritisation of investment in INNP control. Participants of our survey largely perceived management of Japanese knotweed in domestic gardens to be difficult and the majority reported they would employ 'professional help' if it was present in their garden. Although management of INNP can require investments of time and finance, greater education and awareness of efficient and effective ways to manage INNP could increase peoples' confidence in their ability to respond to them, thereby de-escalating risk perceptions. Additionally, greater involvement of the public in control/eradication of INNP in natural areas has been suggested as a method for educating and increasing engagement of INNP management (Reichard & White 2001).

The results of this study have important implications for how risk is communicated. Whilst we need to highlight and acknowledge the risks and impacts of INNP, we need to communicate risks in a way that avoids hyperbole, does not further exacerbate problems of perception and does not contribute to new problems arising. The media, which was the primary source of public information on Japanese Knotweed in this study, is particularly difficult to regulate. Therefore, it is paramount that government authorities provide clear, detailed and consistent information that are widely available on this topic. Ecologists can also contribute to improving risk communication by writing articles for the media, talking to interest groups, e.g. gardening groups (Reichard & White 2001), and contributing to management advice literature. Ultimately, we must work towards a societal understanding that the vast majority of occurrences of INNP on domestic property can be dealt with without unreasonable or excessive cost and anxiety, and that their presence is one of many considerations when purchasing property (RICS 2012). Achieving this will greatly assist with efforts to minimise the ecological and economic impacts of INNP in domestic gardens, as well as the wider landscape.

Table 7.1 Summary of responses to open questions following the question: “If you found a property to buy that was near perfect but had Japanese knotweed in the garden, would you continue with the purchase?” Where participants gave more than one reason their responses were recoded under multiple codes.

Response	Codes for reasons given (with examples):	N =
Yes (would proceed) 20.4% (n = 41)	• No answer given for this part of the question.	11
	• It can be controlled / eradicated it without too much difficulty. (E.g. “Can't be that bad”).	25
	• Have other priorities. (E.g. If really liked the property wouldn't matter, garden is secondary).	3
	• Don’t know enough to be concerned. (E.g. “Ignorant, so wouldn't be concerned”).	2
No (would not proceed) 23.4% (n = 47)	• No answer given for this part of the question.	11
	• It is problematic to control / eradicate. (E.g. “Too difficult to get rid of”).	15
	• Control / eradication is expensive. (E.g. “costly to get rid of it”).	8
	• It can spread and is invasive. (E.g. “Concern about spreading”).	6
	• It will affect chance of obtaining a mortgage and future sale-ability of the property. (E.g. “Would make it very difficult to sell”).	5
	• It has ecological / environmental impacts. (E.g. “Due to its impact upon the environment”).	3
	• It might cause structural damage. (E.g. “nightmare to get rid of, causes structural damage”).	2
	• Its presence might make it difficult to get insurance for the property. (E.g. “you may not get insurance/mortgage”).	2
Under certain conditions 34.8% (n = 70)	**Codes for conditions given (with examples):**	
	• No answer given for this part of the question.	11
	• Only if the Japanese knotweed was being treated. (E.g. “Steps taken to eradicate it”, “was gone before moved in”).	26
	• It is dependent on how much there is and how easily it can be treated. (E.g. “if small amount that could be easily eradicated”).	17
	• If the price of the property was reduced. (E.g. “discount on sale”).	6
	• Would need to find out more about the risks Japanese knotweed might pose and the various treatment options. (E.g. “find out more about threats”).	6
	• Would want professionals to be involved in the treatment process (E.g. “Get professional help”).	5
	• It would depend on the cost of eradication/control. (E.g. “Depends how much it would cost to eradicate”).	4
	• It would depend on the distance that the Japanese knotweed was from the property. (E.g. “dependent upon distance from property”).	4

Table 7.2 Commercial costs of disposal of Japanese knotweed from one of the main landfill companies operating in Cornwall. The disposal company retains the gate fee, whilst the landfill tax goes to the government, part of which fund environmental projects.

	Cost per ton		
Material type	**Gate fee**	**Landfill Tax**	**Total**
Plant material from above ground	£86	£80	**£166**
Soil containing >1% root system and rhizome	£36	£80	**£116**
Soil containing <1% root system and rhizome	£36	£2.50	**£38.50**

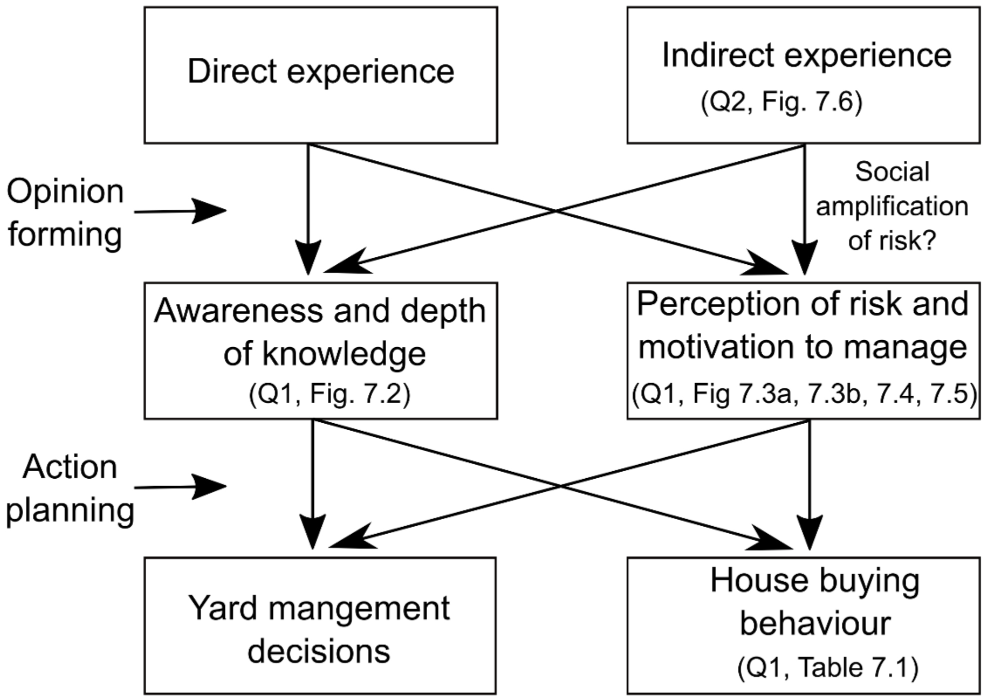

Figure 7.1 Framework for potential ways in which direct and indirect experience could Influence opinion forming, action planning and decision making in relation to INNP in yards. The figures and question that link to each section are referenced.

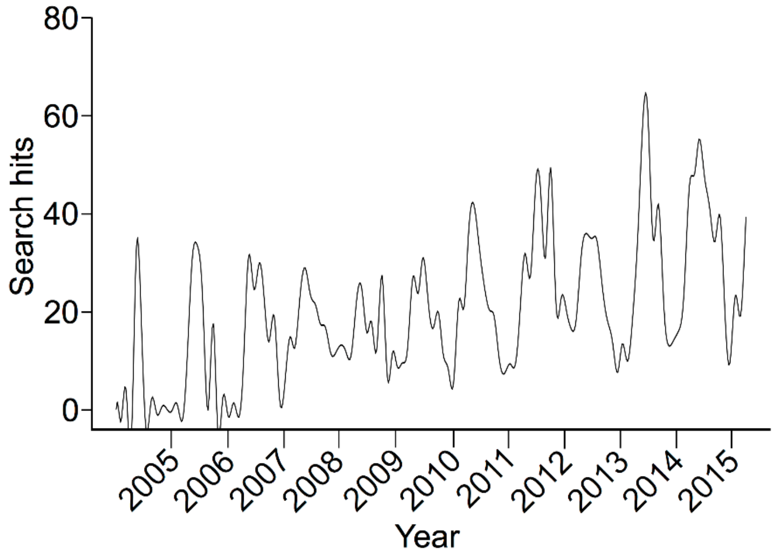

Figure 7.2 Temporal trend for relative number of searches for 'Japanese knotweed' using Google search engine in the UK from 2004 to 2015. A loess smoothing was applied to improve interpretability of the long-term trend (R Core Team 2016).

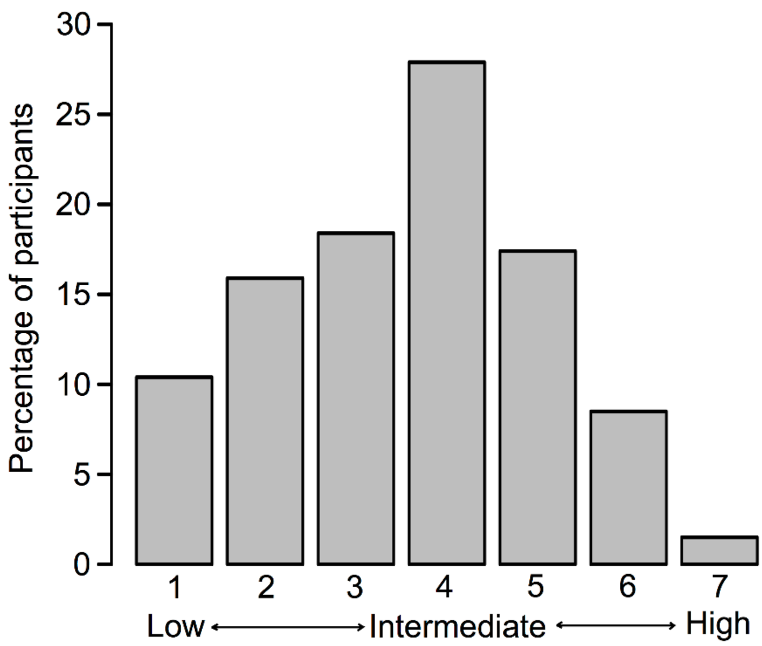

Figure 7.3 Results of survey for self-reported levels of knowledge about Japanese knotweed.

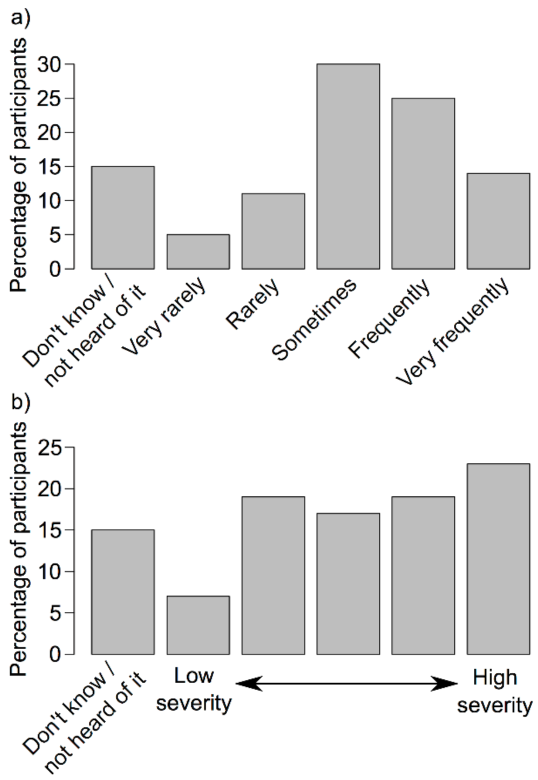

Figure 7.4 Results of survey for questions a) 'how frequently do you think Japanese knotweed occurs on domestic properties in Cornwall?', and b) 'if Japanese knotweed was identified on a property, how severe do you think the consequences could be?'

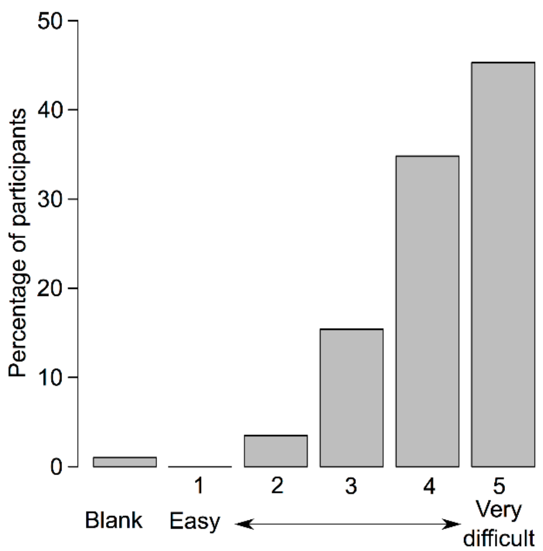

Figure 7.5 Results of survey for perceived level of difficulty to eradicate Japanese knotweed from domestic garden.

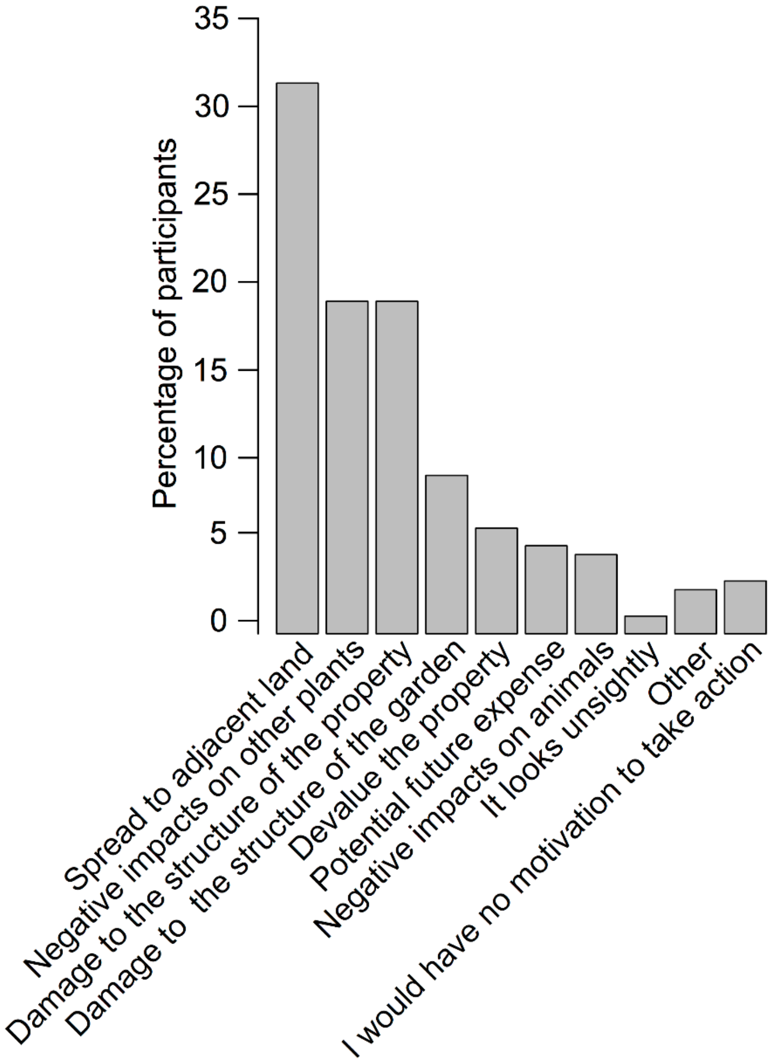

Figure 7.6 Results of survey for main reason participants reported for being motivated to control Japanese knotweed (could only choose one).

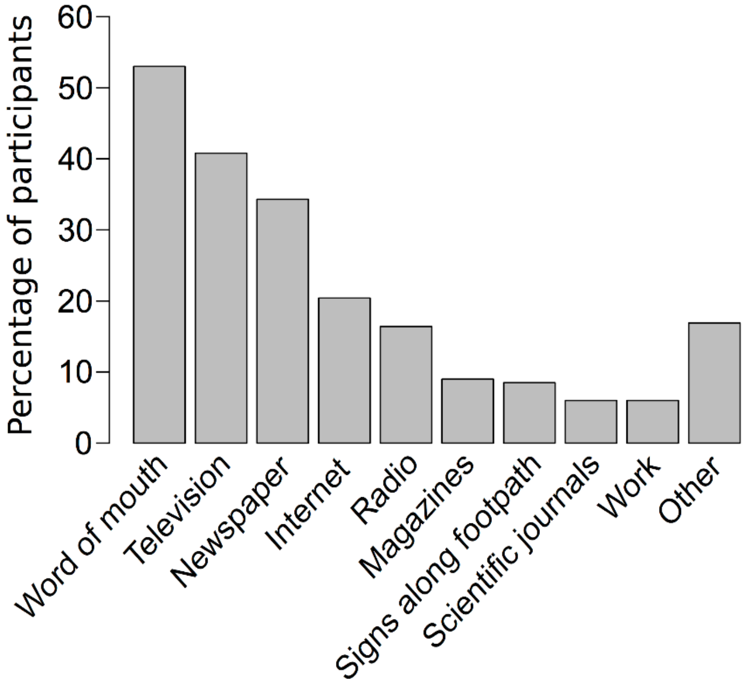

Figure 7.7 Results of survey for sources respondents heard about Japanese knotweed from (they could select multiple answers).

Chapter eight

General discussion

8.1 Introduction

As human populations and associated resource consumption grow, people are having an increasingly significant impact on the earth's ecosystems. One of the greatest environmental consequences of this is the increased movement of plants. This thesis aimed to explore the implications of the influence of increasingly human-dominated landscapes for the spread and impacts of invasive non-native plants (INNP). Greater understanding of the role of humans in the spread and impacts of INNP is important to conserve biodiversity, derive the human well-being benefits that nature can deliver, provide guidance for policy and awareness campaigns and inform management decisions. Using Japanese knotweed as a case study, this thesis used an interdisciplinary approach to advance scientific knowledge around this topic. Key findings include:

- The most important variables predicting the presence and abundance of Japanese knotweed are the build environment (building density), followed by biophysical variables (minimum and maximum temperature), followed socio-economic variables (socio-economic status of the population).
- The abundance of invasive and naturalised species was significantly higher in soil sourced from gardens than from housing developments.
- Less than 20% of a sample of the public could identify Japanese knotweed.
- There is large variation within the information available from different internet-based sources about the impacts and management of Japanese knotweed.
- Differences in perceived risk of Japanese knotweed depend on people's occupation, their direct experience of the species in a domestic context, their geographical proximity to the risk, their age and level of education.
- The magnitude and frequency of the risks Japanese knotweed poses in domestic gardens are much lower than anticipated based on media coverage, and compared with public perception.

8.2 Invasive non-native plants in a human-dominated landscape

8.2.1 Linking different stages of invasion

The different chapters of this thesis apply to different parts of the framework presented in the introduction (Figure 1.1). The plant invasion process varies depending on the spatial and temporal scales considered and can be viewed as a cyclic process, i.e. the processes causing a plant to spread can be the same as those that introduce it to a completely new area. The cycle can be self-perpetuating unless interventions at the appropriate stages in the process are implemented.

To manage effectively INNP, their spread and impacts need to be considered at all stages of invasion and across the full range of spatial and temporal scales. Consideration of the most effective management interventions at the 'introduction' stage is critical, as prevention is always more cost effective than a reactive response (Davies & Sheley 2007). We must however, accept that at the country level, eradication of many INNP is near impossible. Therefore, to reduce the ecological and socio-economic impacts of INNP we must focus on reducing opportunities for local introductions. Many chapters in this thesis considered how humans are contributing to local introductions and ways to mitigate these. For example, chapter three considered how viable seeds and rhizomes of INNP are being moved around within soil.

A critical aspect of managing INNP at all stages of invasion is monitoring (Simberloff *et al*. 2013), as this provides an important early warning system. At the establishment and invasion stages monitoring provides data on rates of spread and abundance. These data can be used to predict where INNP may invade next, where they will be most abundant and problematic, and to evaluate the effectiveness of management strategies (Vicente *et al.* 2016). However, continuous large scale monitoring is expensive (Nichols & Williams 2006). One solution that has been proposed is to use a model-based framework, incorporating multiple sources of information to identify areas where monitoring would be most effective (Vicente *et al.* 2016). Chapter four (plant identification) highlights the role of citizens in monitoring in the wider environment as well as in domestic gardens. Chapters five (weeds on the web), six (risk perceptions) and seven (INNP in domestic gardens) consider if social amplification of risk is occurring, which, if it is, might result in some people being less forthcoming about submitting records of INNP, and therefore challenge the reliability of citizen monitoring approaches.

8.2.2 Implications for policy and awareness campaigns

A recurring theme throughout this thesis is how the research can inform policy and awareness campaigns. For example, chapter four and six identify socio-demographic predictors of plant identification knowledge and risk perception of INNP respectively. These can both be used to inform awareness campaigns. A key challenge in this regard is to make sure the research is read by people who have the power and willingness to implement it, as the spread and impacts of INNP, like many other conservation issues, is competing with many other pressing human needs (Buckley 2016).

Publishing the chapters of this thesis in peer reviewed journals is an important step in achieving impact. However, alternative publication forms and collaborations with appropriate organisations will maximise the chances of this research being impactful. At the local level, collaborations with local government authorities can help research achieve impact; for research presented in this thesis this is Cornwall Council. Indeed, some of the research presented here was only possible due to collaborations with Cornwall Council, in particular chapter two (anthropogenic drivers), for which they supplied the majority of data for. As part of this two-way collaboration with Cornwall Council, once completed, they will be sent a copy of this thesis.

For research to achieve impact at both local and national scales it is important that the research is also presented in a format accessible to non-specialists. At a national level, one way this is achieved successfully is the short documents produced by the Parliamentary Office of Science and Technology that summarise research findings in a policy context, called POSTnotes (www.parliament.uk/mps-lords-and-offices/offices/bicameral/post). Inspired by POSTnotes, I produced an infographic about INNP within Cornwall to summarise the topic for anyone wishing to learn more about it (Appendix 8.1).

8.2.3 Alternative solutions

This thesis focuses on the conventional methods of INNP control – chemical and mechanical. There are, however, alternative solutions to controlling INNP. Biological control is one option that has been carried out for a number of species, and is currently being trialled for Japanese knotweed in the UK (Shaw *et al*. 2009). Biological control has risks, i.e. the control species might impact native species. If, however, the correct steps are taken to minimise these risks, it has the potential to be extremely useful in controlling INNP, particularly in ecological sensitive areas, such as protected areas (van Driesche & Center 2013). The extent of the research and trials preceding the release of a potential biological control candidate for Japanese knotweed in the UK (Shaw *et al*. 2009) demonstrates the level of detail pursuits for biological control agents for other INNP should aspire to.

Another alternative solution for INNP control that have utility is to find creative practical uses for them. For example, making furniture out of them (e.g. big-sage *Lantana camara,* in India; Sandilyan *et al.* 2016), or eating them (e.g. Garlic mustard *Alliaria petiolate,* and Kudzu *Pueraria montana;* Nuñez *et al.* 2012). A quick internet search will reveal a range of sweet and savoury recipes for Japanese knotweed. In a world where food security is an increasing concern we should give this idea serious thought. Some sources suggest that INNP may even have health benefits, although evidence for this is scarce (Sandilyan *et al.* 2016).

8.2.3 Japanese knotweed as a case study

Japanese knotweed was chosen as a case study for this thesis because it is well known, widespread in the UK, and has significant ecological, as well as socio-economic impacts. It is a particularly relevant INNP to study in the context of a human-dominated landscape as it was originally intentionally introduced and its main form of spread is via rhizomes that are largely moved by human activities. Currently the same range of socio-economic impacts Japanese knotweed has in the UK do not occur elsewhere in its geographic range, nor by other INNP within the UK. This leads us to the question: will other invasive plants have similar socio-economic impacts in the future? Or will Japanese knotweed have similar socio-economic impacts outside the UK in future? This is difficult predict. Although in several chapters I suggest certain measures can be taken to improve the accuracy of such predictions. For example, considering the drivers of perceptions of risk, how they are managed (or not) in domestic gardens and careful consideration of how best to communicate risks.

8.3 Social amplification of risk framework

Japanese knotweed seems to evoke curiosity, and often a highly emotive response; it captures people's and the media's imagination. Below is a selection of some of the most noteworthy UK and international newspaper headlines:

- 'Japanese Knotweed WARNING: Warm weather to spark outbreak of home-wrecking monster weed (express.co.uk 2016).
- 'Fight in Fermanagh to stop the monster plant' (fermanaghherald.com 2016).
- 'Japanese knotweed: London to be hit by surge in destructive plant after warm winter' (standard.co.uk 2016).
- 'Japanese knotweed: The plant that can smash concrete, damage houses and survive burning' (Newsshopper.co.uk 2016).
- 'Hogweed and Japanese Knotweed 'are killing Moray countryside'' (pressandjournal.co.uk 2015).
- 'Japanese knotweed: The plant that's eating B.C' (macleans.ca 2015).
- 'Your backyard nightmare: false bamboo is true knotweed' (revelstokemountaineer.com 2015).

This thesis analysed both the media online (mainstream, e.g. websites of printed newspapers, and other e.g. blogs; chapter five [weeds on the web]) and a sample of newspaper headlines more generally (chapter seven, INNP on domestic property) to consider how different sources varied in their portrayal of Japanese knotweed, and how this might be influencing - perhaps inflating - people's perception of risk about this plant. Results suggest that many forms of media over-emphasise the risks of Japanese knotweed on domestic property.

It is easy to understand why Japanese knotweed makes such an attractive media story. First, it is visually impactful. Media stories are often accompanied by striking images of large stands of Japanese knotweed dominating gardens, or of the damage this plant can cause to hard surfaces. Second, it is easy to make reference to popular culture, most notably the 1950s post-apocalyptic novel 'Day of the Triffids'. Third, there is still much we do not know about Japanese knotweed and its impacts. This 'unknown element' makes a media article more enticing. Fourth, there is an element of uncontrollability with Japanese knotweed; you cannot stop it coming onto your land, you can only do your best to control it at an early stage. This adds a fear factor. Fifth, sensationalist headlines, ones that present the world in a threatening and hostile manner (McLeod 1965), are easy to create.

A story with these elements catches the readers' attention, which perhaps has some positive outcomes, such as making people aware of INNP, potentially making identification more likely and encouraging discussion around the topic. However, the chapters within this thesis that address the media portrayal of Japanese knotweed highlight the potential negative consequences of over-emphasis of risks and how it might lead to social amplification of risk. These chapters propose that there are several consequences of social amplification of risk in relation to INNP. For example, as previously mentioned, one consequence might be the potential reticence of reporting INNP to citizen science platforms. A second might be unnecessary expenditure on professional assistance (although decisions regarding necessity of this this vary for other reasons, e.g. time availability, and judgments about when it is required are subjective). A third could be an increased likelihood of taking actions to reduce maintenance, such as paving over gardens, subsequently reducing the wellbeing, biodiversity and ecosystem service benefits that gardens provide.

For all these reasons, it can be difficult to find a balance between raising awareness of risk in a way that captures people's attention and over-stating the risks. Some media outlets achieve this balance better than others. Media outlets which tend to over-emphasise the risks of INNP, and of other environmental and non-environmental risks, are unlikely to change their style. It is not possible to regulate how the media portray INNP, and for the large part we should not try to regulate this as the press should have the freedom to write how they wish. However, there are several things which all media outlets could be encouraged to do: (1) provide links to further information, such as that provided by government organisations. This would encourage people to engage with a more balanced discourse. (2) Acknowledge that each situation, like so many environmental challenges, is highly dependent on social and ecological dynamics (Anderies *et al.* 2007), therefore the solutions to the challenges are very context specific.

Interestingly, chapter six found only limited weak evidence of a correlation between people only hearing about Japanese knotweed from the media and their perception of risk. This highlights the need to consider other ‘amplification stations’. For example, in chapter seven (INNP on domestic property) the role of ecologists and scientists in communicating risks is discussed (Reichard & White 2001). Militaristic metaphors are not uncommon in scientific writing. Although if used infrequently the consequences may be minimal, their use in scientific literature should not be applied thoughtlessly. The sixth chapter also, along with the fifth (weeds on the web), emphasises the role of governmental organisations in mitigating amplification of risk. This relies on effective dissemination of research findings, as discussed earlier.

Although chapter five (weeds on the web) sampled the digital media, there are many other forms of social media, such as Facebook and twitter, that are increasingly important sources of knowledge and can influence perceptions (Brossard 2013). An analysis of social media on the topic of INNP would likely produce interesting results. It is important to remember that many types of media do frequently cover conservation success stories and can play an important role in enthusing and inspiring people about conservation.

To my knowledge, the social amplification of risk framework has not previously been applied to INNP. It has, however, been used to examine perceptions of other ecological risks in human-dominated landscape, for example, Chalera on ash trees in the UK (Pidgeon & Barnett 2013), shark attacks (McComas 2006) and black bear attacks (Gore *et al.* 2005); the last failed to find evidence of social amplification of risk. There are likely many other ecological risks within human-dominated landscape that might benefit from being thought about within the social amplification framework. For instance, re-introduced species, such as the white tailed eagle *Haliaeetus albicilla*, that are being re-introduced into a far more human-dominated world than they existed in previously. In situations where risks are emergent, horizon scanning might be a constructive tool for pre-empting social amplification of environmental risks in an increasingly human-dominated world (Pidgeon & Barnett 2013).

Despite its valuable contributions towards this thesis, the social amplification of risk framework has its limitations. First, the relationships explored within the framework are extremely complex (Pidgeon & Barnett 2013; Figure 8.1), perhaps, therefore, forcing a diverse range of phenomena into this single framework oversimplifies them. Second, the combined measure of frequency and severity might also be a simplification. Risk is a complex thing to measure, and perhaps other dimensions should be examined, such as more intrinsic values, for example the level of anxiety caused by the risk (Pidgeon & Barnett 2013). Third, perhaps it might be misleading to assume there is a true level of risk (Pidgeon & Henwood 2010), as although the danger is real, the risk is socially constructed (Slovic 1999). Even 'experts' disagree over risk, as demonstrated by the variation in responses by those whose occupation involves Japanese knotweed (chapter six). Proponents of the framework argue that it is often more a problem with how some research uses it, rather than with the framework itself (Bakir 2005).

8.4 Experiences of applying an interdisciplinary approach

This thesis used an interdisciplinary approach to address the research objectives; this produced both opportunities and challenges. There is increasing recognition that only through an interdisciplinary approach can we begin to understand and find solutions for many of the pressing complex socio-economic and environmental challenges (Aboelela *et al.* 2007; Phoenix *et al.* 2013). However, difficulties arise due to differences in key characteristics of different disciplines, including differences in methods, epistemologies, research objectives and expected outcomes (Miller *et al.* 2008).

Many chapters within this thesis used methods from the social sciences to answer questions about applied socio-ecological phenomena. Chapters four (plant identification), six (drivers of risk perception) and seven (INNP on domestic property) used questionnaires, a method increasingly familiar in applied ecological research. Chapter five (weeds on the web) used content analysis, a much rarer method in applied ecological research. When submitting thesis chapters to journals careful consideration had to be given to the most appropriate places to submit. The aim was to find journals that were open to research involving social research methods, but that also have high impact and will be read by people in positions to implement change.

Momentum is building towards creating a research environment where interdisciplinary research is easier to do. For example, an increasing number of interdisciplinary departments are being created, and interdisciplinary degrees are now available within the UK that are similar to the American model of major and minor subjects (e.g. https://www.ucl.ac.uk/basc). Furthermore, there is an increasing collection of academic writings highlighting the need for interdisciplinary research and about best practice guidance (e.g. Moon & Blackman 2014; St John *et al.* 2014). There will always be a role for specialism in research, however, in our increasingly complex world we need to ensure we maximise the opportunities to conduct and publish interdisciplinary research and ensure it has meaningful impact.

8.5 Concluding remarks and future directions

This thesis has contributed to scientific knowledge on a diverse range of topics on the theme of INNP in human-dominated landscapes. However, gaps remain. Many of the knowledge gaps are due to the volume and detail of research needed to understand the complexities of human behaviour. To capture the subtle nuances and intricate complexities of some of the human behaviour aspects and perceptions explored in this thesis, qualitative research techniques could be applied. For example, focus groups and in depth interviews could be a useful instrument in disentangling the complex social processes producing varying perceptions of risk and behavioural decisions Furthermore, as I have begun to explore in this thesis, employing methods from other academic disciplines, such as economics and psychology, could help understand complex human behaviour in this context (Reddy *et al.* 2016).

Most chapters of this thesis collected primary data, whereas the second chapter relied on pre-existing datasets of INNP presence and distribution. The availability of plant distribution data is improving, and concerted efforts being made to produce a variety of global databases. However, more needs to be done, especially in regards to long term projects which often struggle to obtain funding. One way to overcome the challenge of limited funds is to prioritise monitoring efforts of invasive species (Vicente *et al.* 2016).

Given the widespread detrimental ecological and socio-economic impacts of some of the most problematic INNP, the conflict is rarely over whether or not to control or eradicate them, but how, where, when, and whose responsibility it is. It is essential that we learn from Japanese knotweed in the UK to minimise the chances of similar socio-economic risks occurring elsewhere and with other INNP. Research within this thesis was carried out in a western context. Clearly, however, human-wildlife interactions are culturally dependent. Therefore, researching the similar topics explored in this thesis in other cultural settings will help disentangle the causal processes.

Many chapters within this thesis focused on management of INNP within gardens. Although gardens are important to consider in terms of INNP spread and impacts, they are just one element of complex management mosaics within which INNP spread and are managed (Epanchin-Niell *et al.* 2010). Therefore, to increase effectiveness of control and eradication of INNP, research needs to consider all types of land owner, private and public, and all individuals who make decisions regarding management of INNP.

This thesis provides an example of how a framework can be developed and used to study the topic of INNP in a human-dominated landscape. Development of similar frameworks can help study other applied complex socio-ecological challenges in human-dominated landscapes. This thesis recognises that humans contribute to both the cause and solutions. One of the greatest causes of INNP, as well as other environmental challenges, is increasing consumption and global population growth. However, achieving a reduction in these is problematic (Buckley 2016). One of the greatest solutions to present day environmental challenges is human willpower and cooperation. It is critical that we continue advancing knowledge of the causes and solutions to environmental challenges to ensure that we can continue to derive the well-being and ecosystem service benefits that nature provides, as well as conserving it for its intrinsic values.

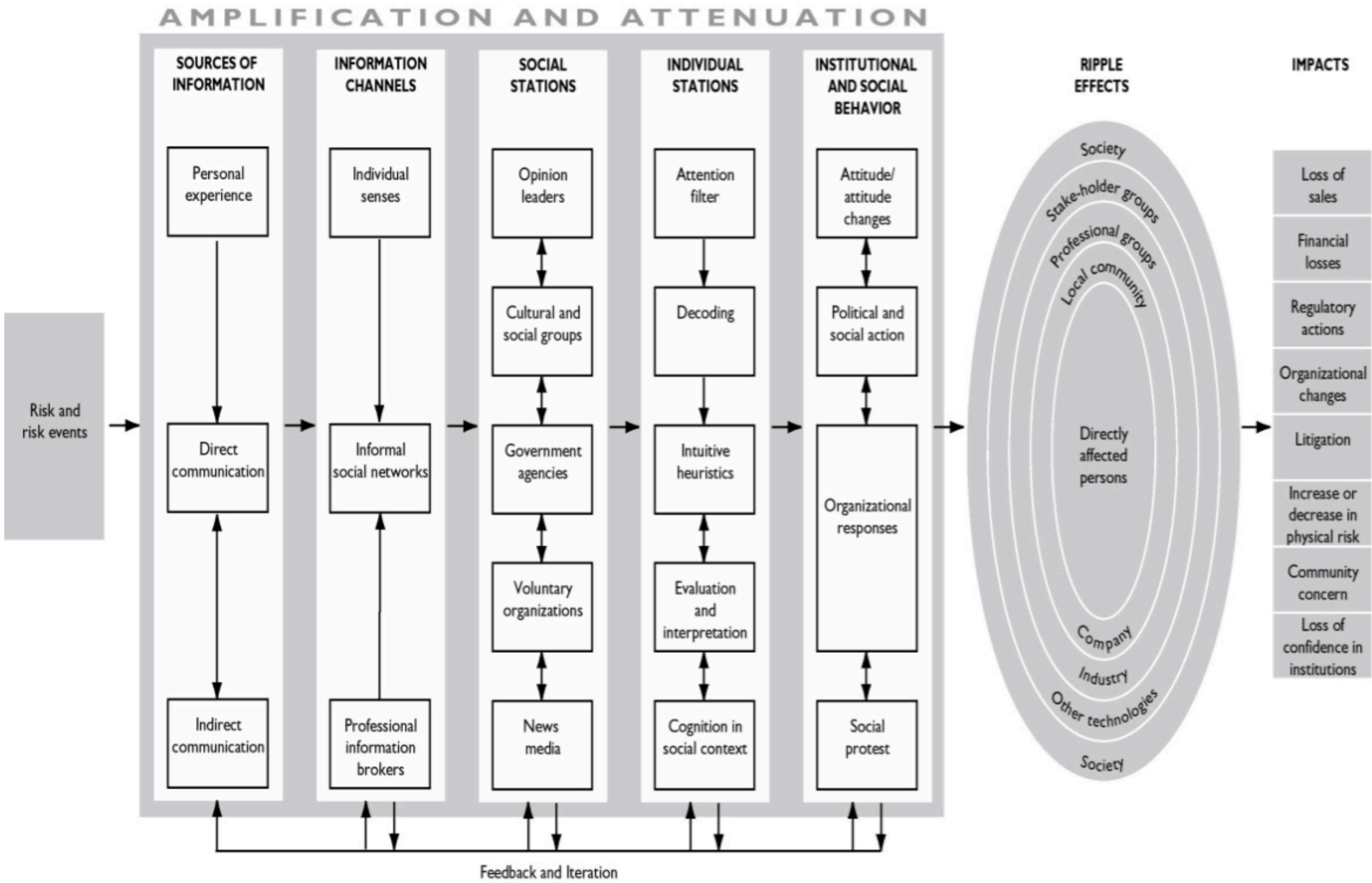

Figure 8.1 Full details of the social amplification of risk framework (Pidgeon & Barnett 2013).

Appendices

Appendix 2: Anthropogenic drivers of an invasive non-native plant (chapter two)

Appendix 2.1 Method and model results using polygon to point approach

Method
Data preparation

The polygon files (n=4185) were converted to point locations using their centroid coordinates and merged with the point data (n=3761 from Cornwall Council; n=44 from NBN). To account for repetition of records within close proximity, multiple points or polygons falling inside the same 10km grid cell were treated as a single occurrence (updated n=7361). Then the number of points within each 1km square was summed.

Statistical analysis

To account for over-dispersion in the data a generalized linear model with a negative binomial distribution was used (Zuur et al. 2009). The land area of the grid square (in m2) after clipping to Cornwall boundary was also included as an explanatory variable to account for any influence of size of land area on the response variable. Models were also built using binomial coding of whether or not the grid square intersected coastline or land boundary with the neighbouring county.

Model averaging was carried out, as described in the main manuscript.

Results

Initial testing for spatial autocorrelation, indicated it was present up to about 10km (Moran's I; I = 0.228, p <0.001).

Table A2.1 Results for model using polygons to point method with land area for a) the global model, and b) model averaged results.

(a)	Without SAC consideration				With SAC consideration			
	Estimate ± SE				Estimate ± SE			
Abundance model	**R^2 = 0.345, AIC = 7741.1 Moran's I = 0.241, P = <0.001**				**R^2 = 0.814, AIC = 6864.9 Moran's I = -0.275, P = 1**			
Index of multiple deprivation	0.388	±	0.054 ***		0.353	±	0.042 ***	
Log(building cover)	1.151	±	0.078 ***		1.102	±	0.061 ***	
Properties socially rented	-0.148	±	0.046 **		-0.133	±	0.037 ***	
Properties privately rented	-0.064	±	0.047		-0.092	±	0.038 *	
Min temperature	0.182	±	0.050 ***		0.211	±	0.041 ***	
Max temperature	-0.141	±	0.051 **		-0.167	±	0.041 ***	
Land area	0.231	±	0.088 **		0.167	±	0.070 *	
RAC	-	-	-		0.954	±	0.029 ***	
(b)								
	R^2 = 0.345, AIC = 7741.1				**R^2 = 0.814, AIC = 6864.9**			
Index of multiple deprivation	0.381	±	0.054 ***	1.00	0.351	±	0.043 ***	1.00
Log (building cover)	1.145	±	0.078 ***	1.00	1.099	±	0.061 ***	1.00
Properties socially rented	-0.146	±	0.046 **	1.00	-0.133	±	0.037 ***	1.00
Properties privately rented	-0.066	±	0.047	0.48	-0.092	±	0.038 *	0.88
Min temperature	0.174	±	0.051 ***	1.00	0.206	±	0.041 ***	1.00
Max temperature	-0.148	±	0.051 **	0.97	-0.169	±	0.041 ***	1.00
Land area	0.232	±	0.088 **	0.90	0.167	±	0.070 *	0.87
RAC	-	-	-		0.954	±	0.029 ***	1.00

Table A2.2 Results of presence/absence global model that used binomial coding of coast as an alternative to land area. 21.9% of the 1km grid-cells intersected Cornwall's border and coastline.

	Without accounting for SAC			Accounting for SAC		
	Estimate ± SE			Estimate ± SE		
	R^2 = 0.209, AIC = 4242.7			**R2= 0.456, AIC = 3177.1**		
Index of multiple deprivation	0.385	±	0.084 ***	0.318	±	0.104 **
Log(building cover)	2.837	±	0.139 ***	2.570	±	0.154 ***
Properties socially rented	-0.446	±	0.078 ***	-0.356	±	0.095 ***
Properties privately rented	-0.197	±	0.079 *	-0.134	±	0.095
Min temperature	0.526	±	0.086 ***	0.537	±	0.103 ***
Max temperature	-0.477	±	0.083 ***	-0.344	±	0.099 ***
Coast	-0.620	±	0.107 ***	-0.588	±	0.128 ***
RAC	-	-	-	2.903	±	0.105 ***

Table A2.3 Results of global model with standardized variables using point to polygon method. SAC is accounted for RAC and SAR error models.

	Without accounting for SAC			Accounting for SAC		
	Estimate ± SE			Estimate ± SE		
Presence / absence model	**R2 = 0.216, AIC = 4314.7**			**R2= 0.463, AIC = 3139.1**		
Index of multiple deprivation	0.405	±	0.084 ***	0.328	±	0.105 **
Log(building cover)	2.836	±	0.144 ***	2.502	±	0.162 ***
Properties socially rented	-0.444	±	0.078 ***	-0.330	±	0.096 ***
Properties privately rented	-0.188	±	0.079 *	-0.114	±	0.096
Min temperature	0.534	±	0.085 ***	0.611	±	0.102 ***
Max temperature	-0.495	±	0.084 ***	-0.353	±	0.100 ***
Land area	0.930	±	0.125 ***	1.138	±	0.144 ***
RAC	-	-	-	2.929	±	0.106 ***
Abundance model	**R2 = 0.094, AIC = 5019.9**			**R2 = 0.146, AIC = 4937.8**		
Index of multiple deprivation	0.476	±	0.077 ***	0.402	±	0.090 ***
Log (building cover)	0.957	±	0.106 ***	0.847	±	0.110 ***
Properties socially rented	-0.147	±	0.067 *	-0.099	±	0.076
Properties privately rented	-0.062	±	0.069	-0.051	±	0.080
Min temperature	0.237	±	0.072 ***	0.241	±	0.091 **
Max temperature	-0.163	±	0.073 *	-0.181	±	0.090 *

Significance codes: 0 = ‘***’; 0.001 = ‘**’; 0.01 = ‘*’; ns = ‘ ‘.

Appendix 3: Sweet flowers are slow and weeds make haste: anthropogenic dispersal of plants via soil (chapter three)

Appendix 3.1 Details of sources of informal network samples.

Garden samples were collected from urban and rural locations, towns included Falmouth, Penryn, Truro, St Austell and Newquay, via the following methods:

- From websites where people sell/give away items (Freecycle, Gumtree and eBay) were searched frequently for adverts for soil (n = 5).
- Adverts were placed in local newspapers, both in print and online (n = 2).
- A request was sent on the University of Exeter social email list for surplus soil (n = 2).
- From trade waste collectors, soil from this source is frequently bound for gardens (n = 2).
- From landscape gardeners moving soil around (n = 3).
- Opportunistically from building sites where soil had been removed to make space for the foundations of a single house. A large quantity of this soil was bound for a friend of the developers' garden (n = 1).

Appendix 3.2 Details of growing method.

The average weight of samples (after removing large stones) was 234.9g (s.e. = 7.3). Samples were then refrigerated at 5 ºC for seven days to encourage germination, then moved to a greenhouse where light and temperature could be controlled. The average minimum greenhouse temperature was 12.9°C (s.e. = 0.15) and the average maximum was 27.12°C (s.e. = 0.28).

Each sample was spread thinly over $400cm^3$ of horticultural silver-sand in a small propagator tray (210 x15mm) with lids to maximise likelihood and speed of germination and reduce contamination opportunities. The location of the samples within the greenhouse was stratified randomly to omit any effect of position on germination and growth. Propagator trays containing only silver sand were randomly located amongst the samples to check for contamination by seeds from the local environment – nothing grew in these trays. Samples were watered daily and fed weekly with a weak nutrient solution (Miracle Gro; Scotts, Marysville, OH).

Appendix 3.3 Details of plant identification and categorization methods

To identify plants to the highest taxonomic level possible vegetative keys (Rose 2006), books (Williams & Morrison 2003) and internet sites (e.g. theseedsite.co.uk) were used.

Non-native plants included both archaeophytes (introduced pre 1500) and neophytes (introduced post 1500). Non-native plants were then classified as invasive if they a) listed in appendix 3 of Roy *et al.* (2012) 'List of species selected for factsheets within the GB-NNSIP' (GB Non-native Species Information Portal), b) listed in appendix 5 of Roy *et al.* (2012) 'Species lists, within broad groups, designated as having a negative ecological or human impact' or c) were classified as invasive in the UK on the CABI Invasive Species Compendium website (www.cabi.org/isc). Non-native species that did not fit any of these criteria were classified as naturalised.

Appendix 3.4 Details of how estimates of the number of viable seeds in the quantity of topsoil required to cover an averaged sized garden were calculated.

We first calculated the volume of topsoil needed for an averaged sized gardens in the UK. We used the average size of domestic gardens calculated by Davies *et al.* (2009) who, using 12 different datasets, calculated the average garden size to be $190m^2$ (95% CI = 173.0, 207.8). The British Standards Specification for topsoil (BS3822: 2015) provides guidance on the depth of topsoil, suggesting 300mm. Therefore:

- Average quantity of soil = 190m x 0.3m = $57m^3$
- Lower confidence interval = 173.0 x 0.3m = 51.9 m^3
- Upper confidence interval = 207.8 x 0.3m = 62.34 m^3

As a rule of thumb landscape gardeners add 20% to this to allow for shrinkage of soil during transportation (Pers. Comm).

- Average quantity of soil = $57m^3$ + 20% = $68.4m^3$
- Lower confidence interval = $51.9m^3$ + 20% = $62.28m^3$
- Upper confidence interval = $62.34m^3$ + 20% = $74.81m^3$

This estimate could then be scaled up using the results of our study for both soil derived from housing developments and domestic gardens.

Housing Developments

On average there were 63.87 individuals in $0.002m^3$ of soil (95% CI = 46.76, 80.97)

- Average number of viable seeds: (68.4 / 0.002) x 63.87 = 2,184,354
- Lower confidence interval: (62.28 / 0.002) x 46.76 = 1,456,106.4
- Upper confidence interval: (74.81 / 0.002) x 80.97 = 3,028,682.9

Garden samples

On average there were 58 individuals in $0.002m^3$ of soil (95% CI = 27.49, 88.51)

- Average number of viable seeds: (68.4 / 0.002) x 58 = 1,983,600
- Lower confidence interval: (62.28 / 0.002) x 27.49 = 856,038.6
- Upper confidence interval: (74.81 / 0.002) x 88.51 = 3,310,716.6

Table A3.1 List of plants identified in the samples.

Species	Perennation	Native, Neophyte or archaeophyte	Number of plants:		
			Total	Housing development samples	Garden samples
Acer pseudoplatanus	Perennial	Invasive	2	2	0
Agrostis capillaris	Perennial	Native	52	52	0
Agrostis spp	Perennial	Native	90	75	15
Anagallis arvensis	Annual	Native	16	3	13
Anthoxanthum odoratum	Perennial	Native	4	1	3
Aphanes arvensis	Annual	Native	1	0	1
Aquilegia vulgaris	Perennial	Native	15	0	15
Atriplex patula	Annual	Native	1	0	1
Betula pendula	Perennial	Native	3	0	3
Buddleja davidii	Perennial	Invasive	254	30	224
Campanula portenschlagiana	Perennial	Naturalised	3	1	2
Cardamine flexuosa	Perennial	Native	7	2	5
Cardamine hirsuta	Annual	Native	4	2	2
Carex spp	Perennial	Native	118	15	103
Cerastium fontanum	Perennial	Native	6	4	2
Chenopodium album	Annual	Native	32	7	25
Chenopodium polyspermum	Annual	Native	8	0	8
Chenopodium rubrum	Annual	Native	2	0	2
Cirsium arvense	Perennial	Native	2	2	0
Crepis capillaris	Perennial	Native	3	3	0
Crocosmia aurea X C. pottsii	Perennial	Invasive	5	0	5
Cruciata laevipes	Perennial	Native	1	0	1
Cymbalaria muralis	Perennial	Naturalised	27	0	27
Cynosurus cristatus	Perennial	Native	3	2	1
Dactylis glomerata	Perennial	Native	19	19	0
Digitalis purpurea	Biennial	Native	31	2	29
Epilobium ciliatum	Perennial	Invasive	24	6	30
Epilobium hirsutum	Perennial	Native	1	0	1
Epilobium montanum	Perennial	Native	6	3	3
Epilobium spp	Perennial	Native	30	18	12
Euphorbia helioscopia	Annual	Naturalised	1	0	1
Festuca spp	Perennial	Native	105	98	203
Filago minima	Annual	Native	2	0	2
Galium mollugo	Perennial	Native	5	0	5
Geranium robertianum	Annual	Native	1	0	1
Glechoma hederacea	Perennial	Native	1	0	1
Holcus lanatus	Perennial	Native	74	48	26
Hypericum perforatum	Perennial	Native	3	1	2
Hypochaeris radicata	Perennial	Native	1	1	0
Jacobaea vulgaris	Perennial	Native	16	16	0
Juncus spp	Perennial	Native	121	107	14
Lamium amplexicaule	Annual	Invasive	2	2	0
Lapsana communis	Annual	Native	4	4	0
Lepidium coronopus	Annual	Native	19	3	16
Leucanthemum vulgare	Perennial	Native	1	0	1
Linaria purpurea	Perennial	Naturalised	1	0	1
Lolium perenne	Perennial	Native	3	2	1
Matricaria discoidea	Annual	Naturalised	3	3	0
Nicotiana alata	Annual	Naturalised	2	0	2

Oxalis corniculata	Perennial	Invasive	7	0	7
Persicaria lapathifolia	Annual	Native	9	4	5
Persicaria maculosa	Annual	Native	14	12	2
Pilosella officinarum	Perennial	Native	5	4	1
Plantago lanceolata	Perennial	Native	2	1	1
Poa annua	Annual	Native	47	42	5
Polygonum aviculare	Annual	Native	11	11	0
Ranunculus repens	Perennial	Native	95	85	10
Raphanus raphanistrum	Annual	Naturalised	1	0	1
Rubus fruticosus agg.	Perennial	Native	1	0	1
Rumex acetosa	Perennial	Native	1	0	1
Rumex spp	Perennial	Native	76	69	7
Sagina procumbens	Perennial	Native	90	26	64
Silene dioica	Perennial	Native	41	32	9
Sinapis arvensis	Annual	Invasive	4	3	1
Solanum lycopersicum	Perennial	Naturalised	1	1	0
Soleirolia soleirolii	Perennial	Naturalised	1	0	1
Sonchus spp	Perennial	Native	3	2	1
Stachys arvensis	Annual	Naturalised	1	1	0
Stachys sylvatica	Perennial	Native	11	4	7
Stellaria holostea	Perennial	Native	7	7	0
Stellaria media	Annual	Native	10	8	2
Taraxacum campylodes agg	Perennial	Native	2	2	0
Teesdalia nudicaulis	Annual	Native	1	1	0
Trifolium dubium	Annual	Native	8	5	3
Trifolium repens	Perennial	Native	7	5	2
Tripleurospermum indorum	Annual	Invasive	1	1	0
Urtica dioica	Perennial	Native	79	44	35
Veronica persica	Annual	Naturalised	39	4	35
Viola arvensis	Annual	Naturalised	3	3	0
Unidentified a	-	-	1	1	0
Unidentified b	-	-	1	1	0
Unidentified c	-	-	1	1	0
Unidentified d	-	-	1	1	0
Unidentified e	-	-	2	0	2
Unidentified f	-	-	1	0	1
Unidentified g	-	-	1	0	1
Unidentified h	-	-	1	0	1
Unidentified i	-	-	1	0	1
Unidentified j	-	-	1	0	1

Appendix 3.5 Details of how species were categorized and weights/volumes calculated. Three different *Epilobium spp* were identified (*E.ciliatum, E.hirsutum* and *E. montanum),* as well as additional *Epilobium spp* that could not be identified. All four were all counted within the species counts for individual samples as there are multiple species that *Epilobium spp* could have been*. Epilobium spp* was recorded as native, as that is what the majority of species were.

Table A3.2 Details of total individual plants and species and in all, housing market and informal network samples.

	Total		Housing market		Informal	
Number of:	**Individual plants**	**Species**	**Individual plants**	**Species**	**Individual plants**	**Species**
Total	1828	90	958	67	870	62
Native	1429	60	878	50	551	44
Naturalised	83	12	14	7	69	7
Invasive	305	8	62	6	243	5
No-status (unidentified)	11	10	4	4	7	6

Appendix 4: A rose by any other name: plant identification knowledge & socio-demographics' (chapter four)

Appendix 4.1 Outline of plant identification survey.

Section one: Plant identification skills

Displayed in front of you are 12 plants that are frequently found in UK gardens.

Q1. Please name the plants displayed that are numbered 1 – 12

Q2. Knowing the name of the plant do you think it (or close relatives of) could be native or non-native to the UK?

Plant number	**Name of Plant**	**Do you think the plant (or close relatives of) could be native?** Yes / No / Don't know
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		

Sections two: Attitudes towards plant identification skills

Please read the statements carefully and *circle* the response that most accurately describes how you feel about the statement.

Q3. Knowing the names of plants is important to me.	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
Q4. If given the opportunity to improve my plant identification knowledge I would take it.	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
Q5. I think children should be taught how to identify common plant species.	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
Q6. I have no motivation to learn the names of plants.	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
Q7. I have been taught the names of plants in the past.	Never	A little	Some		A lot

Q8. How were you taught? (Please *circle* all relevant)

By family members School Attending course(s) Self taught

Other……………………………....

Section three: Background information

Q9. How old are you? (Please *circle*)

18 – 29 30 – 39 40 – 49 50 – 59 60+

Q10. What is your gender? (Please *circle*)

Female Male

Q11. What is your highest level of education you have completed? (Please *circle*)

No formal qualifications
'O' level, GCSE, *or equivalent*
'A' Level, AS Level, *or equivalent*
Further education or vocational training (e.g. BTEC, City and Guilds)
First degree (e.g. BSc, BA)
Higher degree (e.g. MSc, MA, PhD, PGCE, post-graduate certificates/diplomas)

Q12. Are you a member of any environmental, conservation or gardening organisations?

Yes (please select from list) No

National Trust
Local Wildlife Trust
Woodland Trust
Friends of the Earth
Royal Botanic Gardens
World Wildlife Fund
Royal Society for the Protection of Birds
Greenpeace
RHS
Other(s) (please specify)

____

Q13. Do you have a garden? (Please *circle*)

Yes No

Q14. Where do you currently live? (Please circle) Cornwall Rest of UK

Table A4.1 Results from global models. See Table 4.1 in main manuscript for descriptions of explanatory variables.

	Estimate	**Std. Error**	**z value**	**P-value**
a) Ability to correctly name plants				
(Intercept)	-0.288	0.209	-1.378	0.168
Age (30-39)	0.553	0.176	3.147	0.002
Age (40-49)	0.837	0.135	6.222	<0.001
Age (50-59)	1.140	0.142	8.027	<0.001
Age (60+)	1.345	0.151	8.900	<0.001
Gender (male)	-0.679	0.089	-7.649	<0.001
Education (2)	-0.196	0.164	-1.197	0.231
Education (3)	-0.113	0.156	-0.725	0.468
Education (4)	0.002	0.140	0.014	0.989
Education (5)	-0.002	0.148	-0.014	0.989
Member of (one)	0.282	0.113	2.497	0.013
Member of (two)	0.434	0.141	3.068	0.002
Member of (three)	0.655	0.152	4.305	<0.001
Garden (yes)	0.282	0.150	1.874	0.061
Lives (rest of UK)	-0.256	0.096	-2.657	0.008
b) Ability to classify plants as native or non-native				
(Intercept)	0.606	0.198	3.066	0.002
Age (30-39)	0.094	0.192	0.490	0.624
Age (40-49)	0.119	0.146	0.818	0.414
Age (50-59)	0.153	0.152	1.012	0.312
Age (60+)	-0.007	0.157	-0.044	0.965
Gender (male)	0.191	0.094	2.024	0.043
Education (2)	0.105	0.170	0.618	0.537
Education (3)	0.085	0.153	0.556	0.579
Education (4)	0.195	0.141	1.379	0.168
Education (5)	0.295	0.150	1.966	0.049
Member of (one)	-0.063	0.111	-0.564	0.573
Member of (two)	0.110	0.149	0.737	0.461
Member of (three)	0.110	0.148	0.747	0.455
Garden (yes)	0.206	0.160	1.288	0.198
Lives (rest of UK)	-0.065	0.097	-0.667	0.505

Appendix 5: Weeds on the web: conflicting management advice about an invasive non-native plant (chapter five)

Appendix 5.1 Details of codes relating to part (i) - analysis of all documents. For references see Table 5.1.

a) Discussion of problematic traits

These are the traits of Japanese knotweed that make it problematic in its introduced range.

Japanese knotweed...

1. *Grows fast*.

   If the document included information about how Japanese Knotweed can grow and spread rapidly, either generally or by stating figures. Documents needed to go beyond saying simply that it is invasive, and use words that imply fast growth, such as 'vigorous'.

   E.g. "Japanese knotweed is an impressive species that grows rapidly" (Japanese Knotweed Ltd.)
2. *Grows tall*.

   If the document included information about the height that Japanese knotweed can reach, either generally or by stating figures.

   E.g. "often reaching 2-3 metres in height" (Japanese Knotweed Solutions Limited).
3. *Can regenerate from small fragments*.

   If the document included information about how very small fragments of Japanese knotweed rhizome can grow into new plants, either generally or by stating figures.

   E.g. "A piece of rhizome weighing no more than 0.7 g, 300 mm below the surface, can generate new plants" (Norfolk Wildlife Trust)
4. *The plant can survive extreme conditions / grow in a wide variety of habitats*.

   If the document included information about how Japanese knotweed is adapted to withstand harsh ecological conditions such as drought, or that it is adapted to grow in a diverse range of habitats.

   E.g. "it can grow with no discernable signs of stress in a variety of soil types, no matter how poor, with pH values ranging from 4.5 to 7.4" (Japanese Knotweed Ltd.)
5. *Rhizomes that can survive extreme conditions*.

   If the document included information about how Japanese knotweed rhizomes can withstand exposure to extremely low temperatures or high salinity and still be able to regenerate.

   E.g. "Its rhizomes can survive temperatures of −35 °C (−31 °F)" (Bloomingdale).
6. *Rhizomes can survive extended dormancy periods.*

   If the document included information about how Japanese knotweed rhizomes can remain underground for many months, even years, before emerging and growing into a new plant.

   E.g. "Rhizomes can remain dormant for many years (up to 25 years) only to re-emerge" (KleerKut).

7. *Has roots that extend a long way vertically and/or horizontally*.

   If the documents included information about the potential extensiveness of Japanese knotweed's root system, referring to vertical spread, horizontal spread, or both).

   E.g. "the plants underground rhizome (root) system will penetrate up to 3m downwards and fan out up to 7m in any direction from each and every stem" (Japanese Knotweed Eradication Ltd.)

b) Discussion of problems caused

i) Direct socio-economic problems

These directly affect the human environment by physically altering either natural or human-made structures.

Japanese knotweed can…

1. *Cause damage to gardens.*

   If the document included information about how Japanese knotweed can affect the success of garden planning and planting.

   E.g. "the invasive nature of the plant can ruin well-planted and well-stocked gardens". (Royal Institute of Chartered Surveyors).

2. *Increase flood risk.*

   If the document included information about how the presence of Japanese knotweed can increase the risk of flooding. This could arise from damage to hard flood defences, increased erosion of the riverbank or dead stems causing blockages to water flow, weirs or sluices.

   E.g. "dead stems can cause blockage to watercourses that leads to flooding" (Snowdonia National Park).

3. *Damage hard manmade structures.*

   If the document included information about how Japanese knotweed can exploit weaknesses in hard materials such as tarmac and concrete, which can lead to damage to a range of structures such as pavements, buildings, foundations and retaining walls.

   E.g. "it can cause damage to roads, buildings, concrete, drains etc." (Land Tech)

4. *Reduce visibility.*

   If the document included information about how the rapid and dense growth of Japanese knotweed can disrupt visibility by blocking road signs and sight lines.

   E.g. "Many roadside verges and hedges are infested with Japanese knotweed… obscuring signs and visibility". (Cornwall Council).

5. *Trap litter and vermin.*

   If the document included information about how the dense stands of Japanese knotweed can trap litter and/or attract vermin.

   E.g. "Accumulation of litter in mature stands" (Japanese Knotweed Ltd.)

6. *Have a negative aesthetic impact.*

   If the documents included information about how Japanese knotweed is unattractive.

   E.g. "aesthetically displeasing" (Japanese Knotweed Ltd.)

7. *Cause trip hazards.*

If the document included information about how Japanese knotweed can cause damage to pavements, which in turn causes trip hazards.

E.g. "Rhizomes can also cause trip hazards in pavements" (British Records Centre).

8. *Impact recreational activities.*

   If the document included information about how, on riverbanks and footpaths, Japanese knotweed can impede recreational activities, largely by restricting access.

   E.g. "Populations on riverbanks can cause difficulties of access for walkers, boaters and anglers." (British Records Centre).

9. *Cause a fire hazard.*

   If the document included information about how, during dry summer months, the stems of Japanese knotweed pose a fire risk.

   E.g. "It also creates a fire risk during the summer months" (Japanese Knotweed Control Ltd.)

10. *Presence on riverbanks can lead to soil erosion.*

    If the document included information about how, when growing on riverbanks, Japanese knotweed can cause erosion of the soil, as the plant dies back in the winter leaving a mass of dead stems exposing bare soil.

    E.g. "When it dies down in the winter the bare earth is prone to erosion, especially along river banks." (High Peaks Borough Council).

ii) Indirect socio-economic problems

These come about because direct anthropocentric effects of Japanese knotweed have subsequent effects on the social environment or have potential associated economic costs.

Japanese knotweed…

1. *Is costly to eradicate or control.*

   If the document included information about how Japanese knotweed can result in high economic costs to eradicate or control, either generally or by stating figures.

   E.g. "established populations are extremely costly to eradicate" (British Records Centre)

2. *Reduces land / property value.*

   If the document included information about how the presence of Japanese knotweed can devalue property or land.

   E.g. "potentially reducing the value of the property." (Taurus Gardening)

3. *Can cause mortgage problems.*

   If the document included information about how the presence of Japanese knotweed on a property or an adjacent property can lead to complications with securing a mortgage, or even the refusal of a mortgage.

   E.g. "Indeed it can be difficult to obtain a mortgage for a property if there is Japanese knotweed present." (Spey Foundation)

4. *Can cause legal disputes.*

   If the document included information about possible legal disputes that may arise between adjacent landholders when Japanese knotweed is present, or possible legal issues that may arise if Japanese knotweed is

present but concealed when selling a property. Documents had to go beyond simply stating the existence of legislation.
E.g. “However, if it escapes or you cause it to spread to a neighbouring house or garden, you may be liable with litigation against you.” (Knotweed Management)

5. *Can cause delays to planning applications and building development projects.*
   If the document included information about how the presence of Japanese knotweed on development sites can cause severe delays in obtaining planning permission and progressing with the project.
   E.g. “this causes major delays in building projects” (ADK Environmental)
6. *Can cause insurance problems.*
   If the document included information about how damage caused by Japanese knotweed may not be covered by regular insurance.
   E.g. “most insurers will not cover damage caused by Japanese knotweed”. (KleerKut)

iii) Negative ecological impacts

These are effects that have negative consequences for other flora and fauna, biodiversity or ecological processes. Impacts that were subsequently dismissed due to lack of evidence were excluded.

Japanese knotweed can:

1. *Cause a change in biodiversity*
   If the document included information about how it can impact biodiversity. Documents had to discuss either changes in species richness, species abundance, *species composition* or use word ‘biodiversity’.
   E.g. “Japanese knotweed, *Fallopia japonica*, can have devastating impacts to our biodiversity” (Ecology Escapades)
2. *Trophic interactions*
   If the document included information about how it can impact food webs. Documents had to include the term ‘trophic interactions’, ‘food web(s)’ or ‘food chain(s)’.
   E.g. “...seriously impacting on the delicate balance of local food chains.” (Invasive Weeds Agency)
3. *Have a negative effect on animals*
   If the document included information about how it can have a negative effect on animals.
   E.g. “It offers a poor habitat for native insects, birds and mammals” (Cardiff Council)
4. *Have a negative effect on plants*
   Can have a direct or indirect negative effect on other plants by outcompeting for light, water, nutrients etc. or shading other plants.
   E.g. “shades out native plants” (SEPA)

Table A5.1 Author classifications and list of documents included in analysis.

Document name	Web-link
Environmental NGOs: Produced by a registered charity with conservation or gardening focus.	
Botanical Society of Britain and Ireland (BSBI)	http://sppaccounts.bsbi.org.uk/content/fallopia-japonica-f-sachalinensis-f-x-bohemica
Garden Organic	http://www.gardenorganic.org.uk/organicweeds/downloads/fallopia%20japonica.pdf
Norfolk Wildlife Trust	http://www.norfolkwildlifetrust.org.uk/Wildlife-in-Norfolk/Species/Plants/Japanese-knotweed.aspx
Plant Life	http://www.plantlife.org.uk/wild_plants/plant_species/japanese_knotweed
Royal Horticultural Society (RHS)	http://apps.rhs.org.uk/advicesearch/profile.aspx?pid=218
Spey Foundation	http://www.speyfisheryboard.com/spey-foundation-japanese-knotweed/
Wildlife Trusts	http://www.wildlifetrusts.org/species/japanese-knotweed
Invasive Species Scotland	http://www.invasivespeciesscotland.org.uk/japanese-knotweed-fallopia-japonica/
Control Companies: Produced by a company providing services in Japanese knotweed control and eradication.	
ADK Environmental	http://www.adk-environmental.co.uk/4_JAPANESE_KNOTWEED.pdf
Bloomingdale	http://www.bloomingdaleireland.com/invasive-weed-removal/japanese-knotweed/
Corvus Wildlife Management	http://corvusconsulting.com/invasive_weeds.html
Eco Control	http://www.ecocontrol.co.uk/what-is-japanese-Knotweed.asp
Invasive Weeds Agency	http://japaneseknotweed.com/
IVM	http://www.knotweed-uk.com/index.html
Japanese Knotweed Control Ltd.	http://www.japaneseknotweedcontrol.com/japanese-knotweed-what-do
Japanese Knotweed Eradication Ltd.	http://www.japaneseknotweederadication.co.uk/
Japanese Knotweed Ltd.	http://www.japaneseknotweed.co.uk/
Japanese Knotweed Northern Ireland	http://www.japaneseknotweedni.co.uk/
Japanese Knotweed Removal Ltd.	http://www.japaneseknotweedremoval.co.uk/
Japanese Knotweed Specialists	http://www.japaneseknotweedspecialists.com/What-is-Japanese-Knotweed.htm
Japanese Knotweed Solutions Limited	http://www.jksl.com/
KleerKut	http://www.kleerkut.co.uk/
Knotweed Management	http://www.knotweedmanagement.co.uk/index.php?pageid=2

Landtech	http://www.landtechuk.com/about-japanese-knotweed/
LanGuard Vegetation Management	http://www.languard.co.uk/invasive-weed-management/japanese-knotweed/
LK Group	http://www.thelkgroup.com/invasive_plant_management/japanese_knotweed.php
Manor Estates Ground Care	http://www.manorestates.co.uk/japanese-knotweed-removal.php
MITIE	http://www.mitie.com/services/specialist-services/landscaping/grounds-maintenance/japanese-knotweed
PBA Solutions	http://pba-solutions.com/sites/default/files/jk.pdf
Phlorum	http://www.phlorum.com/what-is-japanese-knotweed.html
Southern Ecological Solutions	http://www.southernecologicalsolutions.co.uk/invasive-species/japanese-knotweed-control-japanese-knotweed-treatment-and-removal.html
Taurus Gardening	http://www.taurusgardening.com/japanese_knotweed_treatment.asp
TCM	http://www.t-c-m.co.uk/Terrestrial-Invasive-Weeds/Japanese-Knotweed/Japanese-Knotweed-Identification-amp-Information/inf_5.html
Thompson Habitats	http://www.thomsonhabitats.com/page/japanese-knotweed-fallopia-japonica
TP Knotweed Solutions	http://www.tpknotweed.com/
Vertase FLI Ltd.	http://www.vertasefli.co.uk/japanese-knotweed-treatment-c58.html
Wise Knotweed	http://www.wiseknotweed.com/
Government organisations - National: Produced by a government organisation that acts at a national level, e.g. the Centre for Ecology and Hydrology or by a devolved administration.	
Scottish Environmental Protection Agency (SEPA)	www.sepa.org.uk
British Records Centre	http://www.brc.ac.uk/gbnn_admin/index.php?q=node/202
Centre Ecology and Hydrology (CEH)	http://www.ceh.ac.uk/sci_programmes/documents/JapaneseKnotweed.pdf
Environment Agency (2006) Knotweed Code of Practice	http://www.environment-agency.gov.uk/homeandleisure/wildlife/130079.aspx
Non-native Species Secretariat (NNSS)	https://secure.fera.defra.gov.uk/nonnativespecies/factsheet/index.cfm
Northern Ireland Environment Agency	http://www.doeni.gov.uk/niea/japanese_knotweed-commonly_asked_questions__2_.pdf
Welsh Government	http://wales.gov.uk/docs/det/publications/120109japaneseknotweeden.pdf

Government Organisation – local: Produced by a government organisation at a regional level, such as a county council, city council or national park authority.	
Argyll and Bute Council	http://www.argyll-bute.gov.uk/node/31432
Ashfield District Council	http://www.ashfield-dc.gov.uk/ccm/navigation/environment/environmental-protection/injurious-weeds/japanese-knotweed/
Birmingham City Council	www.birmingham.gov.uk/
Bridgend Council	http://www.bridgend.gov.uk/web/groups/public/documents/form/001909.pdf
Burnley Council	http://www.burnley.gov.uk/site/scripts/documents_info.php?documentID=134&categoryID=418&pageNumber=8
Camden Council	http://www.camden.gov.uk/ccm/content/environment/waste-and-recycling/disposing-of-non-recyclable-waste/japanese-knotweed---what-to-do-with-it.en;jsessionid=809511A564B54DDBA771F3F129106569.node2
Cardiff Council	http://www.cardiff.gov.uk/content.asp?nav=2868%2C4407%2C6166&parent_directory_id=2865&id=10799
Cornwall and Devon Knotweed Forum info leaflet	http://www.cornwall.gov.uk/default.aspx?page=19740
Cornwall Council	http://www.cornwall.gov.uk/default.aspx?page=13789
Derry City Council	http://www.derrycity.gov.uk/Biodiversity/Japanese-Knotweed#.UVw97pOLiSo
Devon County Council	http://www.devon.gov.uk/index/environmentplanning/natural_environment/biodiversity/japanese_knotweed.htm
Dudley Metropolitan borough Council	http://www.dudley.gov.uk/resident/environment/countryside/green-care/japanese-knotweed/
Gelding Council	http://www.gedling.gov.uk/wasterecyclingenvironment/environmentalhealth/smellsodoursothernuisance/japaneseknotweed/
Glasgow City Council	http://www.glasgow.gov.uk/index.aspx?articleid=5100
Hammersmith and Fulham Council	http://www.lbhf.gov.uk/
High Peaks Borough Council	http://www.highpeak.gov.uk/hp/council-services/parks-and-open-spaces/japanese-knotweed
Leicester City Council	http://www.leicester.gov.uk/your-council-services/ep/planning/conservation/biodiversity/habitatadvice/japanese-knotweed/
Medway Council	http://www.medway.gov.uk/environmentandplanning/conservation/treemanagement/trees-pestsanddiseases/japaneseknotweed.aspx

Merton Council	http://www.merton.gov.uk/environment/openspaces/japanese-knotweed.htm
Rotherham Council	http://www.rotherham.gov.uk/info/200084/recycling_rubbish_and_waste/1374/japanese_knotweed/1
Sheffield County Council	https://www.sheffield.gov.uk/.../Sheffield-Invasive-Species--pdf--1-8
Shropshire Council	http://www.shropshire.gov.uk/environmentalhealth.nsf/open/CE7E3A0BCFA72B49802576F000389CE9
Snowdonia National Park	http://www.eryri-npa.gov.uk/the-environment/invasive-species/japanese-knotweed
Solihull Metropolitan Borough Council	http://www.solihull.gov.uk/Attachments/DG_Japanese_knotweed.pdf
Southampton City Council	https://www.southampton.gov.uk/s-leisure/parksgreenspaces/japaneseknotweed.aspx#f46-305523-1
Suffolk Coastal District Council	http://www.suffolkcoastal.gov.uk/yourhome/waste/brownbin/knotweed/
Vale of Glamorgan	http://www.valeofglamorgan.gov.uk/living/highways_and_engineering/japanese_knotweed.aspx
Wandsworth Council	http://www.wandsworth.gov.uk/faqs/200023/conservation/answer/77/what_is_japanese_knotweed#a77
Wirksworth Town Council	http://www.wirksworthtowncouncil.gov.uk/media/japanese_knotweed_information_sheet1.pdf
Wokingham Borough Council	http://www.wokingham.gov.uk/safety/pest-control/japanese-knotweed/
Media – Newspapers: Produced and published on the website of a mainstream news source.	
BBC (2005) What's the problem with Japanese knotweed	http://news.bbc.co.uk/1/hi/magazine/4267426.stm
BBC (2011) Japanese knotweed invasion causes Hertfordshire home price drop	http://www.bbc.co.uk/news/uk-england-beds-bucks-herts-15461880
BBC (2013) Derry man prosecuted for growing JK	http://www.bbc.co.uk/news/uk-northern-ireland-21922732
BBC (2010) Insect that fights Japanese knotweed to be released	http://news.bbc.co.uk/1/hi/8555378.stm
Daily mail (2011) Couple are forced to demolish their home	http://www.dailymail.co.uk/news/article-2052337/Hertfordshire-couple-demolish-300k-home-rid-Japanese-knotweed.html
Financial Times (2008) Japanese knotweed invades Britain, August 9 1850	http://www.ft.com/cms/s/0/b48fdeb6-62a8-11dd-8ed5-000077b07658.html#axzz2Q4pyO1kU
Guardian (2009) Bug brings hope for fight against Japanese knotweed	http://www.guardian.co.uk/environment/2009/jul/23/japanese-knotweed-bug-control

Guardian (2009) Could a tiny insect halt the invasion of Japanese knotweed	http://www.guardian.co.uk/science/2009/aug/14/japanese-knotweed-introduction-insect
Guardian (2012) Japanese knotweed The scourge that could sink your house sale	http://www.theguardian.com/money/2012/sep/08/japanese-knotweed-house-sale
Telegraph (2010) Insects to be brought in to control Japanese Knotweed	http://www.telegraph.co.uk/gardening/7398527/Insects-to-be-brought-in-to-control-Japanese-Knotweed.html
Telegraph (2011) Japanese knotweed might just have met its match	http://www.telegraph.co.uk/gardening/8293993/Japanese-knotweed-might-just-have-met-its-match.html
Media – other: Media articles such as blogs, online magazines and articles on general information websites written by a single or small group of authors.	
About.com	http://landscaping.about.com/cs/weedsdiseases/a/knotweed_2.htm
Andy Hamilton Blog	http://www.theotherandyhamilton.com/2012/03/20/cooking-with-japanese-knotweed/
Ecology Escapades Blog	http://ecologyescapades.wordpress.com/tag/fallopia-japonica/
eHow	http://www.ehow.com/about_7435260_japanese-knotweed.html
Gardeners World	http://www.gardenersworld.com/how-to/problems/weeds/japanese-knotweed/473.html
JB Landscapes Ltd.	http://jblandscapesltd.wordpress.com/tag/fallopia-japonica/
This is money	http://www.thisismoney.co.uk/money/mortgageshome/article-2187358/Mortgage-attack-I-struggled-sell-home-Japanese-knotweed.html
UK Wild Flowers	http://www.ukwildflowers.com/Web_pages/fallopia_japonica_japanese_knotweed.htm
Urban Dictionary	http://www.urbandictionary.com/define.php?term=fallopia%20japonica
Environment Magazine	http://www.environmentmagazine.co.uk/features/conservation/281-japanese-knotweed-problem-or-knot
Covered Mag	http://www.gocompare.com/covered/2012/04/know-your-japanese-knotweed/
Property Market: Produced by an organisation or company that is involved with the property market (e.g. solicitors and estate agents).	
Council of Mortgage Lenders	http://www.cml.org.uk/cml/policy/issues/6633

Cripps Harries Hall	http://www.crippslink.com/index.php?option=com_content&view=article&id=174:japanese-knotweed&catid=32:property-disputes&Itemid=537
Evans Bros	http://www.evansbros.co.uk/Downloads/Knotweed.pdf
Property Care Association	http://www.property-care.org/invasive-species
Peter Barry	http://www.peterbarry.co.uk/blog/2012/jun/19/japanese-knotweed-ignore-plant-your-cost/
Poppywell	http://www.popplewellassociates.co.uk/pdf/JK.pdf
Royal Institute of Chartered surveyors	https://consultations.rics.org/consult.ti/japaneseknotweed/viewCompoundDoc?docid=1228212
Warners Solicitors	http://www.warners-solicitors.co.uk/article/195/japanese-knotweed---legal-implications.html

Appendix 6: Drivers of risk perceptions about invasive non-native plants in domestic gardens (chapter six)

Appendix 6.1 Survey questions.

	Section one: Risk perception of multiple items
1.	How **frequently** do you think the following occur on domestic properties in Cornwall?

	Very rarely	Rarely	Sometimes	Frequently	Very frequently	Don't know / Not heard of
Subsidence	☐	☐	☐	☐	☐	☐
Damp	☐	☐	☐	☐	☐	☐
Ivy	☐	☐	☐	☐	☐	☐
Bats	☐	☐	☐	☐	☐	☐
Mundic block	☐	☐	☐	☐	☐	☐
Herring gulls, black-headed gulls etc. (Seagulls)	☐	☐	☐	☐	☐	☐
High flood risk	☐	☐	☐	☐	☐	☐
Large trees close to the property	☐	☐	☐	☐	☐	☐
Radon Gas	☐	☐	☐	☐	☐	☐
Dry Rot	☐	☐	☐	☐	☐	☐
Japanese knotweed	☐	☐	☐	☐	☐	☐

2.	If the following were identified on a property, how **severe** do you think the **consequences** could be?

Low severity — Intermediate severity — High severity

	1	2	3	4	5	Don't know / haven't heard of
High flood risk	☐	☐	☐	☐	☐	☐
Subsidence	☐	☐	☐	☐	☐	☐
Damp	☐	☐	☐	☐	☐	☐
Bats	☐	☐	☐	☐	☐	☐
Dry Rot	☐	☐	☐	☐	☐	☐
Large trees close to the property	☐	☐	☐	☐	☐	☐
Ivy	☐	☐	☐	☐	☐	☐
Mundic block	☐	☐	☐	☐	☐	☐
Japanese knotweed	☐	☐	☐	☐	☐	☐
Radon Gas	☐	☐	☐	☐	☐	☐
Herring gulls, black-headed gulls etc. (Seagulls)	☐	☐	☐	☐	☐	☐

	Section two: Japanese knotweed specific questions

3.	Have you heard of Japanese knotweed? Yes No
4.	Have you ever known Japanese knotweed to be present in any of the following? (**Select all that apply**) ☐ Garden of property you owned and lived in. ☐ Garden of a second home you rent(ed) out. ☐ Garden of second home use(d) for personal use. ☐ Garden of a property you rent(ed). ☐ Garden within approximately a 5km radius of your home. ☐ Garden outside approximately a 5km radius of your home. ☐ Other land type within 5km radius of your home. ☐ None of the above / Don't know.
5.	What is your **perception of the threat posed** by the following issues associated with Japanese knotweed in domestic gardens?

	None	Little	Some	Much	Extensive	No Idea
It can spread to adjacent land.	☐	☐	☐	☐	☐	☐
It can damage the national economy.	☐	☐	☐	☐	☐	☐
It can cause anxiety to the property owner.	☐	☐	☐	☐	☐	☐
It can damage the structure of the house.	☐	☐	☐	☐	☐	☐
It can have negative impacts for animals.	☐	☐	☐	☐	☐	☐
It can devalue the property.	☐	☐	☐	☐	☐	☐
It can be costly to control for the person responsible.	☐	☐	☐	☐	☐	☐
It can damage the structure of the garden.	☐	☐	☐	☐	☐	☐
It can have negative impacts on other plants.	☐	☐	☐	☐	☐	☐

6.	What would be your **primary motivation** for taking action to control Japanese knotweed if present in the garden where you currently live? (**Select only one)** ☐ Concern about damage to structure of the house ☐ It looks unsightly ☐ Concern about damage to structure of the garden ☐ Concern it will spread to adjacent land ☐ Concern about negative impacts on other plants ☐ Concern about negative impacts on animals ☐ Concern it will devalue the property ☐ Concern about potential future expenses ☐ Other (please specify)………………………….. ☐ I would have no motivation to take action.
	Section four: Background information

7.	Which age category applies to you? (**Please circle**) 18 – 29 30 – 39 40 – 49 50 – 59 60+
8.	What is your gender? (**Please circle**) Female Male Other
9.	What is your occupation? If retired, what was your former occupation? …………………………………………..
10.	Which of the following apply to your living arrangements? ☐ Own / have mortgage on home ☐ Rented - private landlord ☐ Rented – agency ☐ Rented - social housing ☐ Live with family ☐ Other …………….
11.	What is the highest level of education you have completed? □ No formal qualifications □ 'O' level, CSE, GCSE *or equivalent* □ 'A' Level, AS Level, *or equivalent* □ Further education or vocational training (e.g. BTEC, City and Guilds) □ University degree. Please state **level** and **subject** ……………………………….……

Appendix 6.2 Method for collating other potential concerns on domestic property and list of particular risks Japanese knotweed can have.

To develop a list of potential concerns on domestic property other than Japanese knotweed we carried out semi-structured interviews in person with estate agents (n = 20), building surveyors (n = 2) and mortgage advisors (n = 4) in May 2015. Interviewees were asked about other potential concerns causing similar problems to Japanese knotweed on domestic property, both biological and non-biological. We used a questioning technique known as 'free listing', where participants were asked to list as many answers as they could think of in response to the question (Bernard 2011). We reviewed the answers and chose 11 frequently occurring items that represented a range of biological (plants and animals), natural hazards and man-made potential concerns for domestic property.

Using the same free-listing technique, interviewees were also asked to list what they thought could be the particular threats Japanese knotweed could have in domestic gardens. These potential threats were combined with the direct and indirect anthropogenic impacts, and ecological impacts that were discussed in internet-based documents regarding Japanese knotweed from a variety of authors.

Table A6.1 Summary statistics for variables included in model exploring drivers of perception of risk. Base categories in model marked by *.

Variable	N =	% =
Direct professional experience		
Occupation = other *	225	68.4%
Occupation involves housing market	49	14.9%
Occupation involves ecology	55	16.7%
Direct domestic experience		
False *	291	88.4%
True	38	11.6%
Indirect experience: if heard only from mass media		
False *	263	79.9%
True	40	12.2%
Proximity to risk: if know Japanese knotweed within 5km		
False *	138	41.9%
True	165	51.2%
Proximity to risk: if own property		
False *	108	32.8%
True	221	67.2%
Socio-demographics: gender		
Female *	162	49.2%
Male	167	50.8%
Socio-demographics: education		
1: ‘O’ level, GCSE, or equivalent or less *	64	19.5%
2: ‘A’ Level, AS Level, or equivalent	31	9.4%
3: Further education or vocational training	60	18.2%
4: First degree or higher	174	52.9%
Socio-demographics: age		
18 – 29 *	61	18.5%
30 – 39	62	18.8%
40 – 49	64	19.5%
50 – 59	62	18.8%
60 +	80	24.3%

Table A6.2 Results of global models for a) how frequently people thought Japanese knotweed occurred on domestic property in Cornwall and b) how severe people thought the consequences of having Japanese knotweed on domestic property in Cornwall could be.

	Estimate	Standard Error	z value	Significance
a)				
Direct professional experience (occupation involves ecology)	-0.34	0.32	-1.08	NS
Direct professional experience (occupation involves housing market)	-1.71	0.34	-5.02	***
Direct domestic experience (true)	0.78	0.33	2.36	*
Indirect experience: if heard only from mass media (true)	-0.53	0.35	-1.52	NS
Proximity to risk: if own property (yes)	-0.08	0.30	-0.29	NS
Age (30-39)	-0.12	0.38	-0.32	NS
Age (40-49)	-0.29	0.42	-0.69	NS
Age (50-59)	0.00	0.43	0.01	NS
Age (60+)	0.10	0.43	0.22	NS
Education (level 2)	-0.63	0.48	-1.30	NS
Education (levels 3)	-0.64	0.39	-1.66	NS
Education (levels 4)	-0.85	0.34	-2.48	*
Gender (male)	-0.29	0.23	-1.28	NS
b)				
Direct professional experience (occupation involves ecology)	0.66	0.32	2.10	*
Direct professional experience (occupation involves housing market)	0.69	0.32	2.18	*
Direct domestic experience (true)	0.09	0.32	0.27	NS
Indirect experience: if heard only from mass media (true)	0.15	0.33	0.46	NS
Proximity to risk: if own property (yes)	-0.04	0.30	-0.13	NS
Age (30-39)	0.85	0.38	2.28	*
Age (40-49)	0.86	0.41	2.08	*
Age (50-59)	0.97	0.44	2.22	*
Age (60+)	1.36	0.43	3.18	**
Education (level 2)	-0.21	0.44	-0.49	NS
Education (levels 3)	0.78	0.37	2.09	*
Education (levels 4)	0.15	0.32	0.47	NS
Gender (male)	-0.26	0.22	-1.17	NS

Significance codes: < 0.001 ‘***’ < 0.01 ‘**’ < 0.05 ‘*’, NS = not significant

Table A6.3 Result of averaged model of only participants whose occupation was ‘other’ for a) how frequently people thought Japanese knotweed occurred on domestic property in Cornwall and b) how severe people thought the consequences of having Japanese knotweed on domestic property in Cornwall could be.

	Estimate	Standard Error	Adjusted SE	z value	Significance	Relative importance
a)						
1|2	-2.91	0.53	0.53	5.48	***	
2|3	-1.66	0.48	0.48	3.46	***	
3|4	0.08	0.45	0.45	0.17		
4|5	1.72	0.45	0.46	3.77	***	
Direct domestic experience (true)	1.13	0.42	0.42	2.67	**	0.96
Indirect experience: if heard only from mass media (true)	-0.46	0.35	0.35	1.32	NS	0.45
Proximity to risk: know within 5km (yes)	0.78	0.28	0.28	2.78	**	0.99
Proximity to risk: if own property (yes)	-0.02	0.31	0.31	0.06	NS	0.23
Education (level 2)	-0.55	0.51	0.52	1.07	NS	0.80
Education (levels 3)	-0.57	0.41	0.41	1.39	NS	
Education (levels 4)	-1.04	0.35	0.35	2.94	**	
Gender (male)	-0.31	0.27	0.28	1.13	NS	0.37
b)						
1|2	-1.23	0.47	0.47	2.64	**	
2|3	0.56	0.44	0.44	1.27	NS	
3|4	1.56	0.46	0.46	3.38	***	
4|5	2.69	0.49	0.49	5.45	***	
Indirect experience: if heard only from mass media (true)	0.74	0.35	0.36	2.07	*	0.77
Proximity to risk: know within 5km (yes)	1.54	0.30	0.30	5.14	***	1.00
Direct domestic experience (true)	0.64	0.42	0.42	1.53	NS	0.53

Proximity to risk: if own property (yes)	0.68	0.34	0.34	1.99	*	0.73
Gender (male)	-0.39	0.28	0.28	1.42	NS	0.48
Age (30-39)	1.06	0.53	0.54	1.96	*	0.24
Age (40-49)	1.31	0.51	0.52	2.53	*	
Age (50-59)	0.86	0.51	0.51	1.68	NS	
Age (60+)	1.06	0.49	0.49	2.16	*	
Education (level 2)	0.13	0.48	0.48	0.27	NS	0.16
Education (levels 3)	0.73	0.41	0.42	1.76	NS	
Education (levels 4)	0.06	0.34	0.34	0.17	NS	

Significance codes: < 0.001 '***' < 0.01 '**' < 0.05 '*', NS = not significant

Appendix 7: INNP on domestic property (chapter seven)

Appendix 7.1 List of questions used in survey and full results.

1a. How frequently do you think Japanese knotweed occurs on domestic properties in Cornwall?

Don't know / not heard of it	15.1%	(n = 34)
Very rarely	5.3%	(n = 12)
Rarely	11.1%	(n = 25)
Sometimes	29.8%	(n = 67)
Frequently	24.9%	(n = 56)
Very frequently	13.8%	(n = 31)

1b. If Japanese knotweed was identified on a property, how severe do you think the consequences could be?

Don't know / not heard of it		14.7%	(n = 33)
Low severity	1.	6.7%	(n = 15)
	2.	19.1%	(n = 43)
	3.	17.3%	(n = 39)
	4.	19.1%	(n = 43)
High severity	5.	23.1%	(n = 52)

2. Have you heard of Japanese knotweed? (Please circle)

Yes	10.7%	(n = 24)
No	89.3%	(n = 201)

3. How would you rate your knowledge of Japanese knotweed? (Please circle)*

I know very little	1	10.4 %	(n = 21)
	2	15.9%	(n = 32)
	3	18.4%	(n = 37)
Intermediate	4	27.9%	(n = 56)
	5	17.4%	(n = 35)
	6	8.5%	(n = 17)
I am an expert	7	1.5%	(n = 3)

4. From which of the sources below have you received information about Japanese knotweed? (Select all that apply).

Word of mouth	53.0%	(n = 107)
Television	40.8%	(n = 82)
Newspaper	34.3%	(n = 69)
Internet	20.4%	(n = 41)
Radio	16.4%	(n = 33)
Magazine	9.0%	(n = 18)
Signs along footpaths	8.5%	(n = 17)

Scientific journals	6.0%	(n = 12)
Work	6.0%	(n = 12)
Other	16.9%	(n = 31)

Responses 'signs along footpaths' and 'work' were not categories written on the questionnaire, but came up frequently under the 'other' category.

5. What would you do if you had Japanese knotweed on your property?

Employ professional help	47.3%	(n = 95)
Treat it yourself	33.8%	(n = 68)
Nothing	3.5%	(n= 7)
Other	15.4%	(n = 31)

6. If you found a property to buy that was near perfect but had Japanese knotweed in the garden / yard, would you continue with the purchase?

Yes, would proceed	20.4%	(n = 41)
No, would not proceed	23.4%	(n = 47)
Don't know enough to answer	21.4%	(n = 43)
Under certain conditions	34.8%	(n = 70)

If conditional, what would be the conditions? (Open answer)
Please give your reason(s) for your response to the question above. (Open answer)

7. How easy do you think it is to eradicate Japanese knotweed from a domestic garden / yard?

Very easy	1	0%	(n = 0)
	2	3.5%	(n = 7)
Intermediate	3	15.4%	(n = 31)
	4	34.8%	(n = 70)
Very difficult	5	45.3%	(n = 91)
	blank	1%	(n = 2)

8. What would be your primary motivation for taking action to control Japanese knotweed if present in the garden / yard where you currently live? (Select only one).

Concern it will spread to adjacent land	31.3%	(n = 63)
Concern about negative impacts on other plants	18.9%	(n = 38)
Concern about damage to the structure of the property	18.9%	(n = 38)
Concern about damage to the structure of the garden	6%	(n = 12)
Concern it will devalue the property	9%	(n = 18)
Concern about potential future expense	5%	(n = 10)
Concern about negative impacts on animals	4.5%	(n = 9)
It looks unsightly	1%	(n = 2)
Other	2.5%	(n = 5)
I would have no motivation to take action	3%	(n = 6)

9. Which age category do you fit into?

18–29	17.8%	(n = 40)

30–39	13.8%	(n = 31)
40–49	16.9%	(n = 38)
50–59	21.3%	(n = 48)
60+	30.2%	(n = 68)
10. What is your gender?		
Female	56.4%	(n = 127)
Male	43.6%	(n = 98)
11. What is your highest level of education?		
No formal qualifications	6.7%	(n = 15)
'O' level, GCSE, or equivalent or less	17.8%	(n = 40)
'A' Level, AS Level, or equivalent	11.1%	(n = 25)
Further education or vocational training	20.9%	(n = 47)
First degree or higher	43.6%	(n = 98)
12. Which of the following applies to your living arrangements?		
Live with family	7.6%	(n = 17)
Own property	67.1%	(n = 151)
Rent – Private	21.3%	(n = 48)
Rent – Social	4.0%	(n = 9)

*From question 3 onwards, percentages are calculated from the proportion of participants who had heard of Japanese knotweed.

Appendix 7.2 Questions asked in semi-structured interviews with estate agents or relators.

1. How many domestic properties have you sold over the past five years?
2. How many, if any, domestic properties that you have sold in the past five years have had Japanese knotweed on or on adjacent land?

   If any Japanese knotweed was present, the following three questions were asked:

a) Was it present on the property for sale or on adjacent land?

b) Do you believe it caused the price of the house to be renegotiated?

c) Do you believe this caused a sale to fall through at any point?

Table A7.1 Results from individual estate agents or relators.

Estimate of properties sold over past five years	Number of cases of Japanese knotweed
150	0
250	0
350	3
350	1
360	4
425	0
500	3
500	1
500	0
540	1
545	0
600	2
600	0
600	12
650	1
700	2
700	0
700	0
750	2
780	2
1000	6
250	0
1200	4
250	1

Appendix 8: Invasive non-native plants infographic

ENVI NOTES

INVASIVE NON-NATIVE PLANTS

IN CORNWALL AND THE ISLES OF SCILLY

Invasive non-native plants originate from a different geographical area to the one they currently occupy, within which they have spread prolifically. Some of these plants have become problematic and can have widespread and serious ecological and socio-economic impacts.

New Zealand pygmyweed
Crassula helmsii

Himalayan balsam
Impatiens glandulifera

Japanese knotweed
Fallopia japonica

ECOLOGICAL IMPACTS

- Can cause a change in biodiversity
- Can outcompete native plants
- Can change species composition
- Can have negative impact for some animals e.g. can alter habitat struture

SOCIO-ECONOMIC IMPACTS

- Can be costly to manage
- Can cause erosion of river banks, leading to increased likelihood of flooding
- Can cause delays to building and development projects
- Can restrict recreational activities e.g. when growing along river banks

Japanese knotweed (*Fallopia japonica*)

- Was introduced into the UK in c.1850 as an ornamental garden plant.
- Is now widespread and problematic throughout much of the UK, and is particularly abundant in Cornwall.
- In the UK it doesn't spread by seed, but vegetatively - pieces of rhizome (root-like stems) produce new plants.
- All plants in the UK probably originate from one clone!
- The problems it causes, especially economic ones, can be particularly acute on domestic property.
- Incorrect management or disposal of Japanese knotweed could be considered unlawful.

Japanese knotweed... ...grows fast, up to 3cm a day | ...can regenerate from 0.7g of rhizome (root) | ...grows tall, up to 3m | ...has roots that can spread 3m deep and 7m horizontally

What is being done about invasive non-native plants?

Research

- Into improved control / eradication methods, including biocontrol using insects.
- Into the impacts they can have and ways to prevent or mitigate against these.

Plant Tracker

Plant Tracker is a phone app that provides pictures and information to assist in recording locations of invasive non-native plants.

To download the app go to this link:
http://planttracker.naturelocator.org/

Education, awareness and advice

It is important to understand the problems they can cause, be vigilant to their presence, know how to identify and how correctly to manage them.

Further information can be found on the Cornwall Council website:
www.cornwall.gov.uk

Pond check

The Environmental Record Centre for Cornwall and the Isles of Scilly offer a free pond check to help identify invasive non-native aquatic plants.

For more information go to this link:
http://www.erccis.org.uk/invasivespecies/Investigate_Invasives_FW

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